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MEMOIRS

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THE GEOLOGICAL SURVEY OF INDIA.

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OF

THE GEOLOGICAL SURVEY OF INDIA

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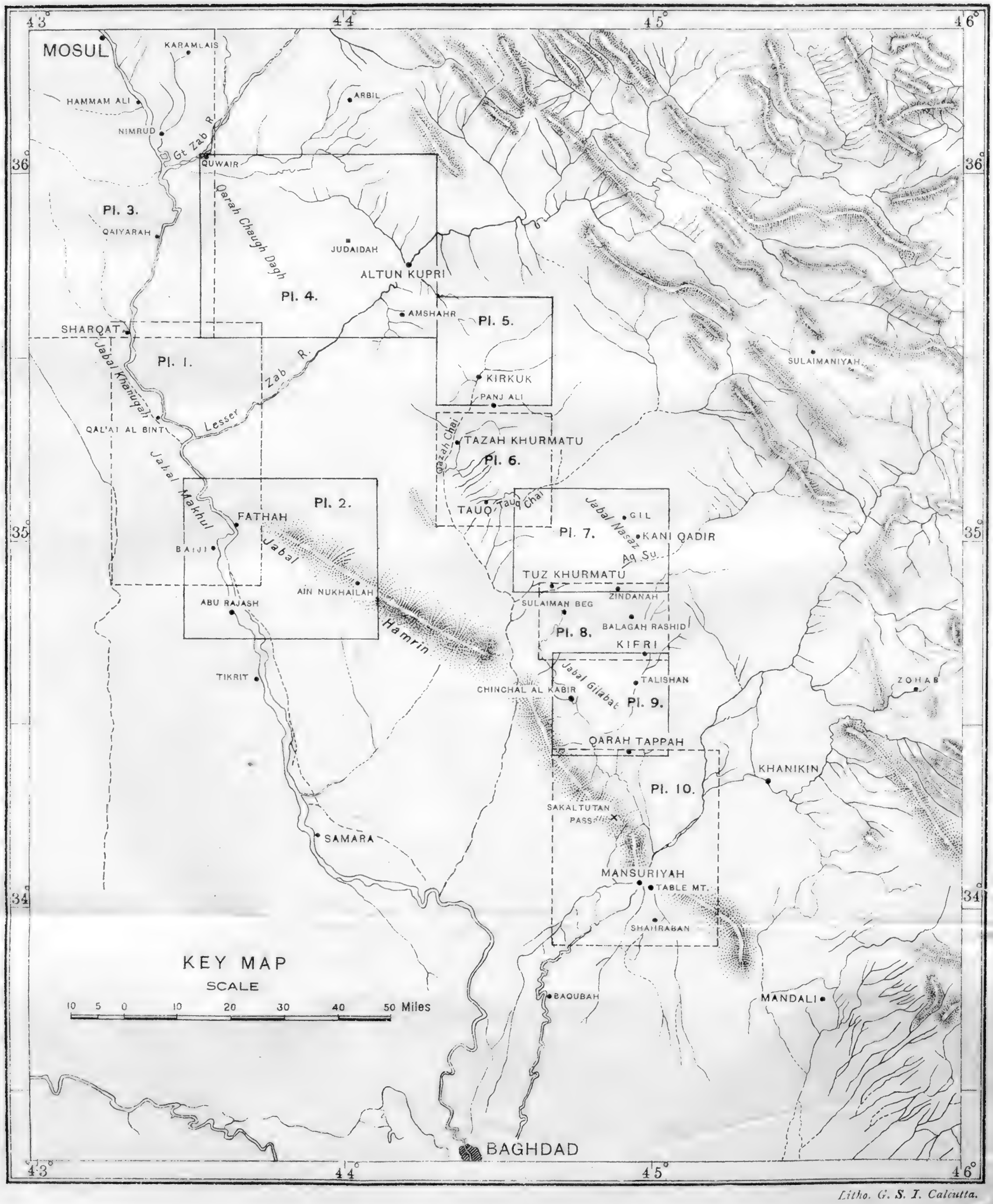

Litho. G. S. I. Calcutta.

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GEOLOGICAL NOTES ON MESOPOTAMIA WITH SPECIAL REFERENCE TO OCCURRENCES OF PETROLEUM.

BY E. H. PASCOE, M.A. (CANTAB.), D.SC. (LOND.), F.G.S., *Director, Geological Survey of India.*

INTRODUCTION.

Itinerary.

During the cold season of 1918-19, I was deputed to make a geological reconnaissance of Mesopotamia. This resolved itself into a survey of as many of the important oil indications as it was possible to include in a five months' tour. The itinerary selected embraced a march from Rail-head—at that time situated near Tikrit—up the right bank of the Tigris as far as Mosul, across the river to Nineveh and thence *viâ* Quwair, Altun Kupri, Kirkuk, Tuz Khurmatu and Kifri to Table Mountain, offsets being made at various points on the way (see Key map, frontispiece). Reports on the individual areas were written *en route* in camp and submitted by despatch-rider, and these reports it is now proposed to publish. As the survey proceeded, a scheme of classification of the rocks was gradually evolved and slight modification of premature views was found necessary, but, beyond the additions and alterations these two results necessitate, I have thought it best to make as few changes as possible, so that the reports may not appear to be anything more than they are, *viz.*, a series of field-notes. I need not enlarge on the difficulties and discomforts of the tour, the incessant violent storms, the unspeakably bad roads, the entire lack of local supplies including fuel, and the unsettled state of the country, except to state that these and the succumbing thereto of two of my camels

caused great delay and made some of the lateral traverses, which it was desired to make, impossible.

My thanks are due to the various political and military officers for all their assistance and courtesy. The relations between my camp and the Arabs and Kurds were, without exception, friendly, a consummation I owe largely to the excellent and efficient work of my interpreter, Habib Kus Elias. Persistent bad weather curtailed work and caused profound discomfort.

Classification.

To render the reports more connected, it is proposed to anticipate to some extent the final conclusions as regards the classification of the rocks. Two Tertiary series only were encountered, the older forming part of Dr. Pilgrim's marine Fars series and the younger a fluviatile series which I at first called the "Red Clay and Sandstone series," but for which I now suggest the less cumbrous name of "Kurd series" provisionally, until we know more precisely to what extent it corresponds to Dr. Pilgrim's Bakhtiyari series. As there seemed no sufficient inducement to split up the Fars beds met with in the various isolated areas, these will be referred to as the Hamrin stage of that series, since they are well exposed in the Jabal Hamrin. The base is not seen. Its uppermost bed in each area has been taken to be the youngest band of white gypsum or fossiliferous limestone, and its strata, especially near the top, include short premature lagoon or fluviatile phases; the latter have been separated off by some as "Passage Beds." The Kurd series, as exposed in the area under review, usually shows four or five distinct phases which can be grouped into two stages, an upper or conglomeratic, and a lower consisting of sandstones and clays. The phases are alluded to as "a" "b" and "c" forming the lower stage and "d" and "e" forming the upper. These phases pass gradually up into each other, and their boundaries are sometimes so ill-defined as to be very difficult to allot, but the phases in the majority of cases are recognisable. No suitable names for them have so far presented themselves with the exception of phase "*d*," which is magnificently developed in the Jabal Nasaz and for which I propose the term "Nasaz zone." A description of these zones will be found in the report on the hills between Tuz Khurmatu and Kifri (pp. 49-51), where the sequence was first seen clearly exposed. Other allusions to them are made in the last or Final Summary Report (p. 69).

REPORT No. 1.—ODD NOTES ON THE COUNTRY BETWEEN TIKRIT AND THE JABAL MAKHUL.

Alluvia.—The river Tigris flows through a belt some three miles wide of very recent low-lying alluvium. This is naturally less salt and much less permeated with gypsum than the higher-lying deposits and is largely under cultivation. It is flanked on both sides by an older alluvium, which forms the rolling plains of Mesopotamia. This older silt is more sandy than that around Baghdad and, north of Tikrit, is practically unstratified and strongly impregnated with gypsum; some of our deep military trenches show in what a large proportion this mineral is present, not only filling small veins and fissures, but impregnating the silt itself. Elsewhere, such as to the south of the Jabal Hamrin this alluvium is stratified. Close to the river and over soft Tertiary conglomerates which crop out occasionally, it includes beds of gravel which occur in the pockety way so characteristic of this form of deposit. The Tertiary conglomerates are exposed in the river cliffs at Tikrit and probably most of the way up to Jift, associated with current-bedded sandrock, the whole forming part of zone "d"—the Nasaz zone—of the fresh-water Kurd series. The alluvium is pebbly for miles inland, the pebbles being derived from underlying conglomerates belonging to the above-mentioned zone.

Road Metal.—The pebbles of the gravel range up to 8 or 9 inches across, the vast majority consisting of siliceous material, chert, siliceous sandstone, milky quartz, etc.; the only other noticeable pebbles are those of an igneous greenstone, rare pieces of homogeneous grey limestone possibly derived from Eocene rocks, and occasionally pieces of black pumice. This gravel—especially the coarser varieties—broken up into angular fragments, would provide road-metal of a high quality. No doubt it occurs lower down the river, nearer Baghdad, and would vastly improve the roads of that city.[1]

Trees.—The absence of trees in Mesopotamia is, I think, not attributable merely to the thriftless cutting down of timber in former times; since on the authority of Herodotus,[2] the Mesopotamian plain has always been practically treeless, but is largely the result of the

[1] This gravel is, I believe, now being exploited at Samara.

[2] *τὰ γὰρ δὴ ἄλλα δένδρεα οὐδὲ πειρᾶται ἀρχὴν φέρειν οὔτε συκέην οὔτε ἄμπελον οὔτε ἐλαίην....*" Herod. Bk. 1. 193. 4.

impregnation of the soil with the salt and gypsum derived from the Fars rocks, which lie not very far below the greater part of the area. Whether any serious effort to grow trees has ever been made, however, seems doubtful; for there should be a good chance of getting suitable kinds to flourish along the river banks and along any network of irrigation canals that may be constructed. I noticed bushes of the Wild Plum (*Zizyphus jujuba*) near Baiji; trees like *Acacia catechuoides* or *Acacia ferruginea*, although not producing much in the way of timber, would probably contrive to exist, as they do in similar regions in Burma and India, and would at least provide fuel, and form a *humus* for other trees. Local patches of soil there must be, practically free from salt and gypsum, such as that around Kut. The neutralisation of the effects of these salts—magnesium sulphate, sodium sulphate, calcium sulphate, sodium chloride, etc.—is one of the problems before the agriculturist of this country, especially north of the deltaic area.

Water.—The prospects of obtaining sweet water by boring in the plain between Tikrit and the Jabal Hamrin and Jabal Makhul are not easy to diagnose. There is such a large element of chance as to the water being sweet or brackish that a geologist can offer no very definite advice. The Kurd series flank the Fars of the Jabal Hamrin and Jabal Makhul, and since it is a fluviatile deposit, it is not at all impossible that its upper strata, consisting of loose conglomerates and sandstones, may contain water which has been protected from the saliferous Fars beds beneath by some impermeable band of clay; thick bands of somewhat sandy clay do occur at the base of this fresh-water series. The probability is that this series underlies the alluvium over large areas, especially areas not very far from the ranges and parallel to them. The chances of reaching this series with the drill by piercing the alluvium and obtaining potable water, at distances not less than say 5 or 10 miles from the ranges, are not unreasonable. Near Tikrit the chances are against the water being sweet, since the Alluvium is full of gypsum.

To exemplify how much a matter of chance this question is, the Ain Khalid and Ain Nukhailah springs may be mentioned; these occur close to the upper boundary of the Fars itself in the Jabal Hamrin, more than half of which range consists of gypsum. The water is only slightly brackish and is perfectly drinkable to people accustomed to the small amount of sulphate present; to those un-

accustomed it is not harmful but has the effect of minute doses of Epsom Salts.

If it is not desired to penetrate completely the Alluvium, visible stream-courses are sites preferable usually for such shallow wells, since there is a considerable amount of underground drainage in the plains, and this would naturally tend to follow established lines.

5th December, 1918.

REPORT No. 2.—THE PROSPECTS OF OBTAINING OIL IN THE JABAL HAMRIN AND JABAL MAKHUL IN THE VICINITY OF THE RIVER TIGRIS.

MAPS.—1 inch=1 mile, Pl. 1, with sections A-A, B-B and C-C.
—½ inch=1 mile, Pl. 2.

INTRODUCTION.

On my way up from Tikrit to Qaiyarah the oil indications at Fathah seemed of such importance as to warrant an extended examination before passing on.

The Jabal Hamrin is a long narrow range projecting from the alluvial plain, and extending from Fathah on the Tigris south-eastwards for over 100 miles to the latitude of Shahraban, and across the river north-westwards for another 37 miles under the name of the Jabal Makhul. The portion under report is that between Ain Nukhailah, 26 miles E.S.E. of Fathah, and Khan Sultaniyah, 23 miles N.W. of the same ancient city and 10 miles S. of Sharqat. The portion of the range delimited is extraordinarily simple and regular, varying from 2 to 2½ miles in width; the highest point of the Hamrin is some 600 feet above the river, while that of the Makhul is probably nearer 800 feet. With the exception of the Tigris gap, this section of the range is not only unbroken, but its crest follows very closely the rise and fall of the anticline of which it consists, producing an unbroken gently undulating sky-line. The Tigris evidently cuts through the range in a weak spot caused by a considerable local sag in the anticlinal crest combined with a change in the direction of the axis from E.S.E.—W.N.W. (more accurately 62° W. of N.—62° E. of S.) on the left bank, to N.W.—S.E. on the

right bank. A sigmoidal curve at Ain Dibs further relieves the monotony.

There is not a single tree in the area or within sight of it, and that portion immediately east of Fathah is particularly barren of grass; towards Ain Nukhailah grass is more plentiful and water less scarce though slightly brackish. The Jabal Makhul also supports more vegetation. Small brown partridges like the Punjab *sisi* are plentiful, especially, in the Makhul, and a few of a larger kind, similar to the Indian *chikhor*, are to be found on the higher slopes; these and their usual companion, the fox, are the only forms of animal life to claim attention.

Exposures are excellent. The ground is much dissected by streams and walking wearisome but not difficult owing to the softness of the strata. The ctopographical maps available were very sketchy and at times ina curate, especially in their contours, but they serve to show in a general way the structure of the area. The geological boundaries, it is hoped, are as accurate as the maps permit. The Alluvium is troublesome in concealing the Tertiaries and has been omitted where possible; to put in the true alluvial boundary would necessitate a separate map. In the upper of the two Tertiary series, the red clays and sandstones have been separated from the sandstones and conglomerates; these two divisions therefore represent the Lower and Upper stages of that series, which I have called the Kurd series.

Rocks.

The rocks comprise a central core of gypsiferous beds belonging to the Fars, flanked on each side by the Kurd series consisting of red clays and sandstones passing up into sandstones and conglomerates. The Mesopotamian Alluvium conceals much of the latter series, but scarcely any of the Fars. Recent gravel is common, and an older conglomerate, probably of Pleistocene age, occurs in small patches at considerable heights near the river.

Fars series.—The predominant constituent of the Fars beds consists of white opaque gypsum, sometimes homogeneous and of a high state of purity, reaching thicknesses of 40—50 feet, at other times stratified with numerous thin lamellae of clay. This deposit is characterised by many underground caverns leached out by percolating water and sometimes several yards deep, which produce the hollow sound so noticeable when walking on these beds. It

weathers in the peculiar way often seen in the case of a homogeneous limestone, the surface becoming scoured by numerous curved channels like those produced by a cheese-scoop. Although such a comparatively soluble mineral, it resists weathering more than the associated beds of clay; in fact its resistance to erosion is somewhat surprising. More than half of the Hamrin range consists of this deposit which, there is every reason to conclude, is a sedimentary one. Associated with it are thin bands of limestone which may be comparatively solid and crammed with obscure shells, especially of a small pelecypod, or may consist of a cellular rock identical in appearance with Mr. Cunningham Craig's "detrital limestone" of the Maidan-i-naftun oil-field of Persia. The latter rock presents the appearance of having been formed of comminuted shell-fragments which have lost their original organic ornamentation and outline, but which are still separated by the original but modified interstices which divided them at the time they were strewn along the bed of the sea; this is the actual oil-bearing rock in the Maidan-i-naftun field, the interstices being filled with oil. In both banks of the river and in some of the small water-courses around Fathah, limestones of this nature are found seeping tarry oil and bitumen. Occasionally recognisable specimens of *Pecten* and *Ostræa* are observable in it. East of Fathah there is probably not more than a total of 50 feet of limestone in separate bands exposed; but in the Jabal Makhul a distinct increase in the amount and a corresponding increase in the steepness and ruggedness of the cliffs are discernible. The Fars beds exposed in this and other localities are identical in character with the lower stage of Dr. Pilgrim's Fars series.

Alternating with the gypsum and limestone bands are beds of sandy clay, sometimes gypseous and marly, frequently permeated with thin laminae of translucent selenite derived from the gypsum, This clay is typically of a light greenish or brownish pink colour and is sometimes—as for instance half-way between Fathah and Ain Nukhailah—stained a conspicuous red with oxide of iron. Both gypsum and gypseous clay in the neighbourhood of oil seepages contain yellow sulphur, and give forth a strong odour of hydrogen sulphide. It is a matter for consideration whether the sulphur and hydrogen sulphide have not originated by the reduction of sulphates by crude oil, one of the results being tar or bitumen (*see* p. 70). Small pockets of red oxide of iron are sometimes to be seen in the gypseous clays.

Since neither range is penetrated very deeply by streams, not more than about 600 feet of the Fars are exposed in the Jabal Hamrin and between 600 and 700 feet in the Jabal Makhul.

Kurd (?*Bakhtiyari*) *series.*—The Fars is succeeded by thick beds of somewhat sandy soft red clay containing near the base two or three isolated layers, an inch or two thick, of selenite derived from the gypsum below; these follow the dip of the clays. One characteristic band, occurring within the first 50 feet, is that of a light bluish unfossiliferous marl, less than a foot thick; this was observed in widely separated areas, for instance at Ain Khalid (near Ain Nukhailah) and near Qal'at-al-Bint some 16 miles N.N.W. of Fathah. Bands of red brown sandstone, at first very thin and argillaceous, soon appear, and increase in size and purity further up in the series until they predominate over the clays in massive current-bedded sand-rock of medium to coarse texture. Near Ain Nukhailah incipient root-like concretions produce a fretted weathered surface on this sand-rock. Thin gravel or conglomerate bands next appear and one of these forms the line of low mound-like hills which stretches practically continuous from the north of Ain Nukhailah to the neighbourhood of the river, where it swings round to the north-west. These mounds have evidently been submerged beneath the alluvial waters and are loosely strewn with gravel which largely conceals the Tertiary beds beneath. This is the highest Tertiary horizon properly exposed, the Alluvium sweeping up its dip-slope. The pebbles in the conglomerates are mostly of siliceous sandstone, chert and white quartz; they are the same as those in the Pleistocene conglomerate and the recent gravels, which have already been described. The whole of this series seems to have offered a surprisingly feeble resistance to erosion, and is nearly always largely masked by alluvium, outcrops of sandstone appearing here and there in the deeper stream-courses.

There is occasionally a decrease in dip passing from the Fars to the red clays of the Kurd series, but in this area there is usually no such change in dip; the highest bed of the Fars, a band of white gypsum, is succeeded by a bed of red clay containing one or two thin layers of selenite and a thin band of bluish marl, and there is the appearance of conformity. I say "appearance," because, although my cursory survey with small scale maps was unable to show that any extensive erosion of the Fars took place before the deposition of the younger series, the change from one to the other is

sudden, sharp and distinct; above the boundary no sedimentary gypsum bands nor fossiliferous limestone occur, the only points in common being a slight resemblance between the clays. It is a line along which one at once suspects unconformity, and I feel convinced that such will be found—perhaps very marked locally—in other localities, and very probably in the area under description when maps of a larger scale are available.

This Kurd series corresponds to the Upper Fars of Messrs. James, Halse, Brown and others, but I prefer to give it no definite assignation provisionally until more of it has been seen for the following reasons. Dr. Pilgrim split up Loftus' "Gypseous Group" into the Fars and Bakhtiyari, chiefly, I take it, because he found this group to consist of a lower marine and an upper fluviatile deposit. The Upper Fars of Dr. Pilgrim is a highly fossiliferous marine deposit with a rich fauna. The red clay and sandstones of the Kurd series of the Jabal Hamrin are unfossiliferous and have every appearance of fluviatile deposits, and extended surveys will probably show that it should be classed as homotaxially equivalent to Dr. Pilgrim's Bakhtiyari Sandstone series, which is described, moreover, as being characterised by red clays at its base and conglomerates further up (*see* pp. 68-69).

The best exposures of the beds is north of Ain Nukhailah where over 3,000 feet can be studied. They are also well seen, though in less thickness, between the Jabal Makhul and the Jabal Khanuqah; the conglomeratic stage is not present here. When not protected by sufficiently thick alluvial deposits, this series produces the most broken kind of ground which is as bewildering to the eye as it is wearisome to the feet, resembling in this and other respects the Irrawadian of Burma.

Pleistocene.—A high-lying conglomerate occurring in the vicinity of the river, at heights varying from about 300 to 500 feet above the Mesopotamian plain, is probably referable to the Pleistocene. It is seen capping the end of the Jabal Hamrin above Fathah, while a small patch occurs on the other side of the river on the Jabal Makhul. On the hills above the Humr Plain south-east of Qal'at-al-Bint it forms a distinct plateau in places. It is not seen in the higher parts of the Hamrin and Makhul ranges. It lies unconformably upon the Fars and it is doubtful whether any perceptible dip is demonstrable. It is sometimes a tough conglomerate several feet thick but is usually soft enough to disintegrate under the hammer and

in many cases is represented only by a loose gravel strewn over the tops of the hills; in the latter case it is only its altitude which distinguishes it from the recent gravel of the Mesopotamian Alluvium. Its pebbles consist of the same siliceous rocks as those forming the Tertiary conglomerates already described, and frequently attain 9—10 inches across, though the average size is nearer 2—3 inches. This conglomerate, derived from the conglomerates of the Kurd series, is evidently a gravel deposit of the Pleistocene ancestor of the present Tigris, which must have flowed over a large part of the continuation of the Jabal Khanuqah overlooking the Humr Plain.

Recent.—The Mesopotamian Alluvium has been referred to in an earlier report. It has interbedded pockets of gravel, which are to be seen on both banks of the river at Fathah, at the north-western corner of the Humr Plain and elsewhere. Its pebbles, derived from the Pleistocene and Tertiary conglomerates, consist of the same siliceous sandstone, chert, quartz, igneous greenstone and rarer pieces of grey limestone: in addition fragments of a blue-black pumice were observed between Fathah and Nukhailah. The Mesopotamian Alluvium covers nearly all the Kurd series, which is not always clearly exposed in consequence; the very broken ground between the Jabal Makhul and the hills above Humr, for instance, really forms part of an alluvial plain through which some of the sandstones may have occasionally projected in the form of low mounds. Near the Fars this deposit contains water-worn blocks of white gypsum. One occasionally gets an impression of slight dip in the alluvium. The boundary mapped is a purely arbitrary one, being the approximate limit of Tertiary exposures.

The New Alluvium fringing the river calls for no remarks.

Structure.

As already stated the Hamrin and Makhul ranges coincide with a remarkably long and persistent, simple anticline. A second anticline commences east of the Humr Plain and continues north-north-westwards in the Jabal Khanuqah. The distance between the two anticlinal axes, which are not quite parallel, varies from $3\frac{1}{4}$ to $5\frac{3}{4}$ miles, the syncline between being occupied by the Kurd series.

The Hamrin-Makhul anticline is slightly asymmetric, the south-western limb being a little steeper than the north-eastern (*see* sections on pl. 1). As the folding movement, in all probability,

came from the north-east, being part of that gigantic system of loops which constitute the Himalayan, the Afghan, Baluchistan and Persian mountain systems, we thus remark a tendency for the fold to be pushed over towards the direction of movement.

The details of the structure are as follows, commencing at the Nukhailah Pass and proceeding north-westwards. The crest of the anticline sinks to a minimum close to and a little east of this pass, east-south-east of which point it is seen rising gently on a very broad, open, round and regular fold. Across the pass the anticline, omitting slight irregularities on the north-eastern slope is practically symmetrical, while the outcrop of the Fars is reduced to about $1\frac{1}{4}$ miles in width. West-north-west of the pass the fold rises very gradually, at first about 2°—3° but becoming less and less for some $2\frac{1}{2}$ miles where it reaches a maximum altitude. Beyond, the anticline pitches in an equally gradual and gentle fashion for another 2 miles, after which it rises again gradually and steadily as far as the word "Jabal" on the $\frac{1}{2}$ inch map, where for two or three miles no perceptible pitch is measurable; at this crest-maximum the Fars outcrop is over $2\frac{3}{4}$ miles in width. It then slowly begins to sink, the pitch gradually increasing to over 5° when a point is reached about a mile from the Tigris where it once more rises very slightly, forming with a short distance of the outcrop on the west bank of the river, a small dome area, which is slightly steeper on its south-western aspect than elsewhere, and whose centre is beautifully shown in the river by concentric ellipses of limestone and gypsum bands, three of the former seeping oil. Up the Jabal Makhul the crest rises, distinctly at first, less and less perceptibly afterwards. Persistent mist prevented my determining the crest-maxima in this range, but there seems to be a long horizontal stretch immediately south of Qalah Jabbar and perhaps another maximum south-south-west of Mushak. Opposite Ain Dibs there is a distinct pitch of 5° to the north-north-west.

With regard to the flanks of the fold, the dip at Ain Nukhailah rises to 40° on each side. Steeper dips occur locally immediately west-north-west, but where section B-B has been drawn (pls. 1 and 2) the general maximum dip on the north-east is about 35°, while that on the south-west is between 35° and 40°. On the south-western flank some 5 miles from Fathah a small subsidiary wrinkle makes its appearance and persists for about 3 miles giving vertical and reversed dips along the Fars boundary; this is probably a result

of the pitch of the fold. This pitch is accompanied by a flattening of the arch which at Fathah is very broad and gentle.

The Jabal Makhul shows considerable asymmetry at first, dips of perhaps 25° (the maximum dip is concealed beneath alluvium) on the north-east being balanced by dips of 65°, 75° and 80° on the south-west. Near Jabbar the asymmetry becomes less, the dip measured reaching 27° on the north-east and 57° on the south-west. Across Ain Dibs we have about 25° average maximum dip on the north-east against 40° on the south-west, the latter flank steepening rather suddenly towards the base of the range. Figures for Makhul must be accepted as approximate only, the river on one side and the alluvium on the other masking the maximum dip. As a whole the crest is broad and rounded in both ranges; in longitudinal section it is also curved.

The river has pierced the range at a weak spot where the crest has sunk to the small low dome between the two crest-minima, and where the direction of the fold somewhat abruptly changes from 62° W. of N.—62° E. of S. to nearly due N.W.—S.E.; dip-faulting may have assisted the river in this. That this gap dated at least from Pleistocene times, is, I think, shown by the presence in its neighbourhood of the conglomerate of that age.

An interesting feature of this and other areas is the "choked" nature of parts of the stream-courses traversing the alluvium. This is probably the result of wind-blown dust and sand drifting into such depressions and accumulating during the frequent dust-storms which characterise the hot dry season.

Petroleum.

Natural Indications.—Seepages of tarry oil and bitumen are too numerous on both river banks around and opposite Fathah to be indicated on the map. Bitumen impregnating earth is to be seen at various horizons, and has frequently been forced up vertical fissures. Three separate oil horizons of seeping cellular limestone can be distinctly traced for some distance, passing from one side of the river to the other. Gouts of dark oil are seen continually floating down the river, and have been collected and utilised by the Sappers; there is a strong odour of hydrogen sulphide on both banks. The water trickling from the small streams into the river are milky with suspended sulphur, and specks and patches of this mineral are locally common in the clays and gypsum; a tarry

oil usually contaminates this water and there is then a confliction of the odours of hydrogen sulphide and that of aromatic hydrocarbons. Similar indications were noticed in a stream-course 2½ miles east-south-east of Fathah on the south side of the range, and others about 5 miles above Fathah on the north-east side of the Jabal Makhul; these are merely instances and there are doubtless others. Their particular abundance at the gap made by the river may be due to disturbance of the strata caused by the twist in the anticline and the pitch of its axis. Seepages are frequently found where a fold pitches, perhaps on account of disturbance in the beds.

Prospects of Boring.—Mr. Lister James divided what he called the Lower Fars of the large Persian Oilfield into three zones, *a*, *b* and *c*, *a* being the oldest. The Hamrin beds seem to agree very closely with his *b* zone, and as the important oil horizons occur in the cellular limestones of the lowest or *a* zone in the Maidan-i-naftun field, there is good reason to suppose that such limestones are within easy access of the drill in the Jabal Hamrin and Jabal Makhul; three at least of these petroliferous limestones, which, in Persia, extend up into James' middle or *b* zone, are perhaps represented by the denuded seeping limestones on the river banks at Fathah. The structure could scarcely be more suitable, the fold being broad, simple, fairly symmetric, gentle, regular and singularly free from faulting, with the possible exception of the vicinity of the gap made by the river, where the crest is too low for any faulting to have disturbed possible "oil pools" in the more likely parts of the anticline. This part of the Jabal Hamrin is not quite fifty miles from the line of strike of the Kirkuk occurrences. Further to the south-east its distance from the Tuz Khurmatu (Palkanah) seepages is less than 20 miles, and still further in the same direction, in the neighbourhood of Table Mountain, this range is about the same distance from the promising oil locality of Naft Khana, north of Mandli.

We have, therefore, favourable geographical position, eminently favourable structure, beds of the same age as those known to be highly petroliferous in the Persian field and within easy reach of the drill, and abundant seepages, though somewhat local, to confirm this. Altogether the prospects are good and warrant tests being made on the highest points of the anticlinal crest, one somewhere opposite the word "Jabal" of "Jabal Hamrin" on the ½ in. map T.C. 225 (pl. 2), and another south of Qalah Jabbar on the summit of the Jabal Makhul (pl. 1). The physiographic crest of the ridges

is usually a little north-east of the anticlinal crest, so that a location on the former would allow for the slight asymmetry. There is a graded road up to the crest of both ranges from the river, by which a boiler and engine could be transported. Water is obtainable just below the Hamrin location on the north-eastern side, probably in sufficient quantity for a boiler in the wet season. At the Makhul location it could be obtained from the river.

It is perhaps premature to draw general conclusions, but the similarity in conditions between this country and the oil regions of India and Burma are worth pointing out. We have a petroliferous series containing saline products and marine fossils, indicative of a dessicated gulf, followed by a fluviatile deposit, the river having in all probability replaced the gulf, just as we have in the Punjab, Assam and Burma. The folds become steeper as we approach the eastern margin of the gulf, *i.e.*, the quarter from which the folding movement proceeded. One is tempted to prophesy "boundary" faulting close to this eastern margin, either in the Lower Tertiaries or along their base; its presence would explain the earthquake shocks which occasionally afflict Mesopotamia.

December, 1918.

REPORT No. 3.—THE PROSPECTS OF OBTAINING OIL IN THE JABAL KHANUQAH SOUTH-EAST OF SHARQAT.

MAP.—1 inch=1 mile, Pl. 1.

INTRODUCTION.

The Jabal Khanuqah is a range of the same structure and comprising the same rocks as the Jabal Hamrin or Jabal Makhul; from the latter it is distant 3 to 6 miles to the north-east, the two ranges being not quite parallel. It is a rock-wave of the same movement which produced the Jabal Makhul, and, like this range, consists of a simple regular anticline exposing a core of Fars beds, succeeded by the Kurd series. The range is unpierced except by three or four small streams at Qal'at-al-Bint, which have taken advantage of a pitch in the anticline and perhaps of the ntinuation of a fault, together with an acute reduction in the width the range due to excessive erosion by the Tigris. The range mmences west of the Humr Plain below Qal'at-al-Bint in the

Humr Hills, and the portion under report extends as far as Sharqat along the right shore of the Tigris, which has eaten its way into the north-eastern limb of the anticline nearly as far as the crest along a distance of about six miles south-east of Sharqat, and beyond the crest for two or three miles at Qal'at-al-Bint. The north-eastern aspect of these parts of the range, therefore, consists of precipitous cliffs exhibiting a fine exposure of the Fars series. The direction of the range is nearly N.W.—S.E.

Rocks.

Fars series.—The Fars is the same gypseous series described in the report on the Jabal Hamrin and Jabal Makhul. Some of the gypsum bands are very massive and thick, reaching thicknesses of 80 or 90 feet; an interesting little "natural bridge" of this mineral over a stream-course, some 15 feet deep, was observed in the Humr Hills. The amount of limestone present is very small. This stone, quarried from this range or from the Jabal Makhul, has been used in the ancient city of Asshur, where blocks of it can be seen in what appears to be the remnants of a quay on the north side, and a similar bastion-like structure on the west; blocks of gypsum seem also to have been used in some of the buildings.

Kurd series.—The Fars is succeeded by the Kurd series (astride of the "Upper Fars" of some geologists), which is largely hidden beneath alluvium, especially in the north-eastern limb of the anticline. The beds are in every way similar to those described, but the higher Conglomerate stage is not present in the syncline between the Khanuqah and Makhul Ranges.

Pleistocene.—The Pleistocene Conglomerate is well seen capping the hills south-east of Qal'at-al-Bint, where its pebbles are cemented into a tough rock. It is also found on the hills overlooking the Humr Plain, close to the river, but is not present on the highest parts of the Humr Hills.

Mesopotamian Alluvium.—The Mesopotamian Alluvium, consisting of the same somewhat sandy silt elsewhere described, at one time swept over the syncline between the Khanuqah and Makhul ranges from Mushak north-westwards, forming a broad plain, most of which has survived. The more southern portion has been deeply dissected and the underlying red clays and sandstones of the Kurd series laid bare, but the surface of the plateau or plain is still represented. The deposits include beds of gravel near the river at Humr and

in the neighbourhood of the Pleistocene Conglomerate. A large number of the stream-courses in the northern half of the plain, as well as those immediately around Sharqat, are "choked" in the way mentioned in a previous report (p. 12), and some of them are being re-cut by the rejuvenescence of the streams.

New Alluvium.—The new Alluvium needs no comment. It fringes the northern aspect of the city of Asshur, so that the river in Assyrian times probably swept round past the cliffs forming the northern face of the city, where the quay-like structures are to be seen, eastwards past the walls of another city, Sudairat, on its opposite bank, forming an S-shaped bend. The bastion or quay on the west may have bordered a creek or dock running northwards into the river.

Structure.

The anticline forming the range is simple, regular, closely coincident with the physical features, and almost symmetrical, the south-western limb, as in the other folds, being a little steeper than the north-eastern near Humr. The anticlinal crest follows practically the crest of the ridge, and the highest point of the former corresponds closely to the highest point of the latter (1,272 feet above sea-level, *see* map, pl. 1). North-west of this there is an almost imperceptible pitch as far as Sharqat, beyond which the fold was not traced, and south-eastwards a more distinct pitch as far as Qal'at-al-Bint. South-east of the latter locality there is a gentle rise to the centre of the Humr Hills, and a corresponding fall further in the same direction. There are two crest-maxima, therefore, of which the more northerly is the higher.

Near Sharqat the dip on each side is very gentle, being not more than 10° or 12°. South-eastwards the maximum dip in the south-west limb increases to about 16° while that in the north-east limb, where not concealed by the river, is about the same, omitting local steepenings. Further south-east the general maximum south-westerly dip is about 15° rising to 20° and 27° locally, and the north-eastern dip about 10°—11°.

The Humr Hills end northwards in a scarp which is so straight as to suggest a fault. Some low mounds, also, along its foot have the appearance of red clays belonging to the Kurd series obscured by alluvium. Fortunately a clean exposure of sandstones and clays belonging to this series was found at the mouth of a small stream

by the "Gogaiyir Rocks," dipping south-west, *i.e.*, apparently under the Fars and thus confirming the presence of an E.—W. oblique dip-fault with a down-throw on the north. The Gogaiyir Rocks consist also of the same sandstone. This fault must be met or crossed by another running N.—S. or N.W.—S.E., since this sandstone series extends no further to the west. The River Tigris has taken advantage of these faults to eat deeply into the range at this point. Since the south-eastern end of these Humr Hills forms a similar straight scarp, it is probable that there is a corresponding dip-fault here also.

Petroleum.

Enquiries elicited no reports of seepages of oil or sulphur, but on two separate occasions I noticed a very slight odour of bitumen near the mouth of the stream draining the northern part of the Humr Hills and issuing at the Gogaiyir Rocks, though I was unable to find any visible hydrocarbon indications.

The structure and age of the rocks exposed are favourable signs respecting the presence of oil, but the prospects of boring obviously depend upon what is found in the Jabal Makhul and upon the possibility that oil horizons were not confined to the upper portions of the exposed Fars beds but occur also in the deeper layers forming the anticline not laid bare by the denuding action of the Tigris. Should oil be found in commercial quantities in the latter range, the Jabal Khanuqah ought also to be tested by a boring on the crest near the highest point of the range, five or six miles N.N.W. of Qal'at-al-Bint. The Humr Hills, in spite of the two faults which do not disturb the crest-maximum, might also be worth limited testing.

December, 1918.

REPORT No. 4.—PROSPECTS OF OBTAINING OIL IN THE JABAL QAIYARAH[1] AND ITS CONTINUATION, THE JABAL NAJMAH.

Maps.—$\frac{1}{2}$ inch=1 mile; Pl. 3.

Introduction.

The Jabal Qaiyarah extends in a general W.N.W. direction from the right bank of the Tigris at Qaiyarah[1] military post which is 35 miles south of Mosul and 22½ miles north of Sharqat. It does not reach the river, but sinks gradually to low ground forming

[1] "Kiara," "Guyara," "Gayarah," "Gaiyarah," and many other forms.

the right bank thereof; there is a faint indication of the range on the left bank. One or two miles north-west of the military post some limestone produces some features of prominence, but the range is not high, and further north-west becomes a mere broad belt of high ground—a series of scattered mound-like hills—till some three miles E.S.E. of Qishlah, where the same limestone commences to rise again and gives still more conspicuity to the range. This portion of the range, though of no great altitude above the plain, is fairly well defined and has been dissected by broad ravines into bluffs and peaks of some distinction. It sinks again further west, but another defined portion can be seen rising about five miles W.N.W. of Qishlah.

The structure is that of a simple anticline which, as usual, follows very closely the rise and fall of the ground, exposing Fars beds flanked by the red clays and sandstones of the Kurd series. Owing to the sketchy nature of the maps available the geological boundaries delineated are somewhat diagrammatic, the only means of locating them being in most cases a compass and watch; that of the Mesopotamian Alluvium is roughly the limit of Tertiary exposures and has no tectonic significance. Exposures along the base of the hills are obscure.

Rocks.

Fars series.—The lowest beds exposed are the Fars, consisting of the usual beds of white gypsum, greenish and red clays, and thin bands of limestone. One of the latter gives conspicuity to the hills above the Oil Station, but further north-west sinks into the featureless part of the range to within three miles of Qishlah, where it again makes itself still more evident, and produces bold bluffs and scarps, the highest point of which rises to 1,284 feet above sea-level—about the same height as the highest point in the Jabal Khanuqah. Not more than 500 feet of this series are exposed at Qishlah and Qaiyarah, and less than this in the intervening country.

Kurd series.—No clear exposures of the red clays and sandstones were noticed on the south-western flank, which is much obscured by alluvium, but there is no doubt that this series underlies the latter deposit along this base of the rising ground. It is fairly well seen on the north-eastern flank, and consists of the usual red clays with selenite and reddish brown current-bedded sandstones,

the latter increasing and predominating as we ascend the series. Near the mouth of a large water-course some seven miles S.S.W. of the Qaiyarah military post, massive sandstones in which two distinct local unconformities are seen, belong to the uppermost horizons of the lower of the two stages into which I have provisionally divided the series; overlying them, is the Conglomerate stage mentioned in the Jabal Hamrin report ('Nasaz zone').

Mesopotamian Alluvium.—The Mesopotamian Alluvium is more argillaceous than it is south of Sharqat, and roads consequently suffer more in bad weather. As usual it includes deposits of gravel near the river and especially above the higher horizons of the series.

New Alluvium.—The New Alluvium borders the river and extends up some of the larger *wadis*.

Structure.

The anticline is a simple, regular, very broad fold, extending in a gently curved line with a general W.N.W—E.S.E. direction; the curve is that of a very flat reversed 'S,' the middle portion running N.N.W.—S.S.E. There being no boat obtainable it was impossible to cross the river and investigate what looked like a continuation of the Fars outcrop flanked on the north by red clays and sandstones; such a continuation is probable.

From the Tigris the anticline rises distinctly to a crest maximum, $1\frac{1}{2}$ miles west of the Oil Station. W.N.W. of this it pitches at an angle which at first is about $1\frac{1}{2}°$, but which soon becomes so small as to be immeasurable, and a long stretch of almost horizontal crest extends as far as the Qishlah hills; there may be a W.N.W'ly pitch along this stretch, but if so, it is extremely slight and probably negligible. Within three or four miles of Qishlah Fort there is a distinct rise which increases to something like $2\frac{1}{2}°$. Northwest of Qishlah there is a pitch to the W.N.W., so that there is another crest-maximum close to the Fort, probably a little higher than that above Qaiyarah. The rise in the range seen four or five miles further still to the W.N.W. no doubt indicates a further rise in the anticline, and according to the map there are others beyond; owing to trouble with a local Sheikh I was unable to work on foot beyond Qishlah, but by the courtesy of the Royal Air Force and kind intermediation of Col. Leachman, Political Officer, Mosul, I was taken by Lieut. Price for a flight over the Jabal Yawan. The anticlinal

fold of the Jabal Najmah, which is a continuation of that of the Jabal Qaiyarah, persists for at least 12 miles further north-west, but not in the same straight line. This is shown correctly by the ½-inch map (pl. 3). Possibly the fold curves into its new alignment along the Jabal Yawan, but from the air the latter appeared to be échelonned on the Najmah Range; if this be correct it constitutes, strictly speaking, a new anticline, or rather two new anticlines, since the échelon appears to be double. Whether curved or échelonned, an anticlinal structure persists over this line.

Furthermore, on passing over a conspicuous mound covering some buried town, and what looked like the site of a ruined village adjacent thereto, I noticed a pool of water forming part of a stream-course, in which was a whitish deposit resembling sulphur and a black deposit of the appearance of tar. My pilot also observed it and agreed with me as to its resemblance to an oil seepage. We were flying at 1,000 feet and may easily have been deceived, as both sulphur and tar have their natural imitations in this country. I record the observation for what it is worth, and my reason for doing so, is its important bearing, if it be a genuine seepage, on the possible extension of this oil field. On the map I located it about half a mile south of the track from Hadhr to Shura just before it crosses the range, eight or nine miles W.N.W. of Qishlah, but Lieut. Price placed it two or three miles further W.N.W.; it occurs on the southern slope of the range (*see* map, pl. 3).

With regard to the flanks of the anticline, slight undulations therein—a result of the breadth and gentleness of the fold—made it difficult to estimate the general average maximum dip, especially on the south-west where alluvium conceals the steeper-dipping beds. West of Qaiyarah the average maximum dip in the south-western limb is probably in the neighbourhood of 15°, rising to 19° or 20° in the Qishlah area. On the north-eastern flank the general maximum dip is probably nearer 10° or 12°, but slight puckers, caused by the weight of the rocks in such a broad gentle arch, bring in local dips of 37°, 20°, etc. For practical purposes the fold may be looked upon as symmetrical, though the Qishlah area shows a slight steepening on the south-west (*see* sections, pl. 3).

The same "choking" of the stream-courses noticed elsewhere (pp. 12 and 16) was observed, and extended up into the Fars outcrop.

Petroleum.

Natural Seepages.—I located four areas where seepages occur, but there may be others.

The first is marked on the ½-inch map as "Naphtha Spring," and consists of three separate patches of bitumen and tarry oil, the two upper being connected by a stream of bitumen. It is impossible to make an estimate approaching any degree of certainty regarding the thickness and amount of bitumen here and elsewhere, owing to our ignorance of the irregularities in the floor on which it lies. It is of course a mere surface deposit supplied by numerous small vents up which the tar producing it oozes; the supply therefore is an easily exhaustible one and will be replaced only after a considerable lapse of time. The uppermost patch of the area in question is irregular in shape, but covers something like 100,000 square feet. An assumption of 6 inches average thickness would give 50,000 cubic feet as the amount present. The middle patch is larger and the richest of the three, being partly covered by a lake of water. It is an oval area of about 400,000 square feet; the thickness is over one foot in places, but taking one foot as the average, the amount present would be 400,000 cubic feet. The lowest patch is not much larger and probably very thin. We may assume it to contain 50,000 cubic feet. The total for the combined area thus becomes 500,000 cubic feet, but it might well be double this or considerably less. There are numerous small vents up which an inflammable gas, consisting largely of hydrogen sulphide, issues, together with a thick black tarry oil in process of being transformed into bitumen; there is every grade, in fact, from a viscous tarry oil, through plastic tar or bitumen, to solid brittle asphalt. Where water accompanies the oil, a pool is often formed in which sulphur is deposited, derived from hydrogen sulphide, of which a strong odour pervades the area. The oil from which the bitumen is produced is, in all probability, derived from some seeping petroliferous limestone beneath the alluvium. Some of the bitumen is mixed with earth, and that of the stream connecting the two upper patches contains many pebbles. The solid brittle asphalt is a form of "manjak;" it resembles in appearance a lignitic coal, but an application of heat will demonstrate the difference, the bitumen melting and emitting the characteristic odour.

The second bituminous area is close to the oil wells, and covers an area perhaps a little larger than the first. The bitumen is thicker

also and probably reaches 2—3 feet in places. 1,000,000 cubic feet is probably not an excessive estimate of the quantity here, and there is considerably more thick oil and gas. In a small water-pool sulphur in some quantity has collected at the bottom; it and the water are disturbed by a curious ebullition, although very little gas reaches the surface, the bulk probably being dissolved by the water, which smells strongly of hydrogen sulphide. Oil was collected here by the Turks, or by the Germans who were in control of the place before the War, and a stone oleoduct has been built out into the middle of the area, with an open channel sloping down towards the margin, along which the oil flowed after being pumped up or raised in some way into the head of the duct.

The third locality is along the river bank close to the military post. This is largely mixed with gravel and mostly dry and "dead," but a few small vents can be found here and there.

The fourth area is of no intrinsic importance and occurs on the north-eastern flank of the range opposite Qishlah. This consists of a little bituminous earth with a faint but distinct smell occurring in two or three places in a small stream-course north of Qishlah Pass. A little sulphur is also present and an odour of hydrogen sulphide. A few yards further down is a spring of water tinged with sulphur.

The question has been raised whether the Qaiyarah bitumen can be used with advantage as fuel. If the supply of oxygen could be regulated by some sort of chimney-device as in an oil-stove, no doubt the smokiness of the flame, which renders it useless for cooking in the open, would disappear, but it would seem more economical to reserve the material for the usual purposes to which bitumen and tar are put (*see* p. 76). Although much of it is mixed with earth, this would not interfere with its fitness for use on roads, and although the supply is limited and perhaps not so great as many are inclined to hope, it should repay exploitation. It could not compete with the liquid oil as a fuel, and of this there is every prospect of large supplies. The bitumen question is a purely minor one and bears no comparison with that of oil.

Prospects of Boring.—Seven borings were made by the Germans before the recent British occupation. Of these, four are producing or capable of producing oil, but to what extent is at present unknown. The other three are "dry," but this may be due to their not having reached the oil horizon through accidents to the holes or other causes. Of the four producing wells one was still in process of construction

and was evidently on the point of entering the oil horizon, as oil has recently commenced to appear at the casing head. This was evidently intended to be a deep test-well, judging from the size of the tools and the amount of casing lying around it, the largest of the latter being 12 inches in diameter. The derrick and machinery are still in place; some of the latter had been damaged before the Turks retreated. The other three wells all flow, although, in the case of two, this is a mere drip. The best well has a considerable pressure and would fill an ordinary kerosene tin in five or six seconds with a black oil containing a certain amount of tar but some petrol as well. Large quantities of hydrogen sulphide are at the same time evolved, rendering the oil-jet almost unapproachable. The three last mentioned wells have tripods over them. They all probably tap the same horizon, but no information is at present available as to their depth, except that derived from a Turkish engineer who, I understand, worked formerly on the field, and who affirms that none of the wells are more than 170 feet deep. This I learnt from Lieut. Club, who also kindly showed me what was to be seen at the Station. The wells are all in the same locality, and about 300 yards apart. There is a small refinery of five stills, for which crude oil was used as fuel, and two condensers, all in working order though of a crude construction. Some of the refined oil was found in drums; it is water-white and smells of naphtha.

Structure, age of the rocks, accessibility to the drill, geographical position, the existence, copiousness and nature of the seepages, and preliminary boring, are all factors so much in favour of the view, as to amount to a certainty, that an oilfield of importance exists here. How far it is likely to extend along the range is not so easy to forecast, but from the result of the boring as far down the pitch of the fold as the existing oil wells are, there is a good prospect of its extending most of the way to the Qishlah rise; there is an odour of hydrogen sulphide perceptible on the south-western flank, four miles east of Qishlah, before the anticline begins to rise again, which may or may not have any significance.

As the crest rose so conspicuously in the Qishlah area, I felt convinced that some natural petroleum indications must exist in that neighbourhood, and on making enquiries from some Arabs there, was pleased to be shown the occurrences of bituminous earth

and sulphur already mentioned. The Qishlah area, therefore, is also promising. The prospects of the hills beyond, right into the Jabal Yawan, depend on the result of experiment at Qishlah. As a preliminary measure I would strongly recommend test wells in the two areas, Qaiyarah and Qishlah. With regard to the former, the present wells are too far down the pitch to give maximum yields. The best location for the first well here should be on the highest point of a long E.—W., flat-topped, table-like hill capped by limestone $1\frac{2}{5}$ mile due west of the incomplete German well with the derrick over it. This hill lies east and a little south of a prominent conical hill (height 882 feet) whose apex consists of the same limestone. The location should be towards the eastern end of the table-like hill, just west of the cairn which marks its highest point. The Qishlah well should be N. or N.N.E. of Qishlah Fort on the crest of the anticline, or 100 yards or so N.N.E. of it. There will in all probability be a less productive if not barren tract between the Qishlah and the Qaiyarah areas and nearer the former than the latter. There is an Arab rumour that the Germans intended boring at Qishlah and actually took machinery out there, but buried it on the Turkish evacuation of Qaiyarah. If so, they must have sought better advice than that which located their present wells. With regard to the latter, the completion of the well they commenced would be a good test of the extent of the oil "pools," and the well has good prospects of obtaining a reasonably good yield. As stated in a former report the oil will probably be found to occur in cellular limestone similar to that which crops out at Fathah.

Two tunnels in the gypseous marls and clays made by the Germans near the Oil Station, are thought to have been attempts to mine for sulphur, but they seem to me just as likely to have been experiments to obtain the true dip and nature of the local strata. Sulphur is widely present but in too disseminated a form to be worth working, though something might be made, in a small way, of the sulphur that collects in the streams and pools already mentioned and also of a copious spring which issues from a cave and flows underground for a short distance beneath a "natural bridge" of gypsum, about a mile N.N.W. of the Oil Station. Sulphur in some quantity is carried down by this water, derived from the hydrogen sulphide which is in solution therein. The supply could be increased by burning a little of the extracted sulphur and passing the gas produced into the water. The recovery of sulphur here

could never be more than a small industry, unless something could be done as well with the hydrogen sulphide which issues with the oil in borings.

6th January, 1919.

REPORT No. 5.—POSSIBILITIES OF OBTAINING OIL IN THE JABAL MISHRAK AND COUNTRY WEST OF HAMMAM ALI.

MAPS.—$\frac{1}{2}$ inch=1 mile ; Pl. 3.

INTRODUCTION.

The term Jabal Mishrak is applied to some hills overlooking the Tigris on its right bank opposite the confluence of the Greater Zab. The range is continued N.N.W'wards towards Minqar somewhat interruptedly by the Tel Sulaiman and other hills with no established name. I propose to include them all under the designation "Jabal Mishrak." It has neither the simplicity nor the same degree of regularity of the ranges hitherto described, and this is paralleled by irregularity in the anticline which it constitutes. The hills commence to rise above Hadra village on the Tigris and merge into high ground N.N.W. of Jahannam towards Minqar, which swings round to the west past Kharrar. Exposures are fairly good except along the western flank, where alluvium has obscured the structure, and, in the south, the boundary line between the Fars and the red clays and sandstones of the Kurd series which succeeds it. North of the Wadi-al-Adbar the Mishrak fold merges into a vast exposure of Fars beds which are never far from the horizontal and roll hither and thither in a somewhat capricious way, though there is always a tendency to preserve a N.W—S.E. direction, which is shared to some extent by the hills. North-west of Hammam Ali, a town 14 miles S.S.E. of Mosul, the ground is considerably broken and the surface littered with limestone fragments. I was much hindered in my examination of the Mishrak area by atrocious weather.

ROCKS.

The rocks comprise the usual core of Fars, which is cut off eastwards by the river Tigris and low-lying alluvium. To the southwest between Shura and Hadra some badly exposed thin reddish sandstone has been assigned to the Kurd series ; beyond this north-

westwards the Fars outcrop is continuous with Fars beds which seem to form another low anticline, south-west of the Mishrak axis. Northwards nothing but Fars, sometimes partially hidden beneath alluvium, is seen as far as Mosul.

Fars series.—The Fars series consists of the usual beds already described in other reports, the prominent physical features south-east of Rassif, those of Tel Sulaiman and the hills around Jahannam being produced by limestone. One of these limestone bands covering a large area S.S.W. and W. of Hammam Ali, caps a thick bed of soft clay, the result being chaos. The clay has given way and the limestone fractured into numerous fragments which lie about at all angles, entirely obscuring the dip; the clay band is largely responsible for the bad road between Shura and Hammam Ali. The only new feature worthy of notice in this series is the advent near the top of some thin bands of sandstone, sometimes reddish, as near Tel Mujman where it is overlain by fossiliferous limestone, or sometimes thin pebbly coarse sandstone full of broken shells underlying a band of white gypsum, as seen near Safatiyah; fragments of the latter type are seen lying about the surface east of Shura. The sulphur and bitumen emanations will be referred to later.

Kurd series.—The red clays and sandstones of the Kurd beds form a syncline between the Jabal Qaiyarah and Jabal Mishrak, pitching to the south-east, and partly interrupted, as far as could be made out, by the end of a low flat anticline pitching in the same direction along a line not far from the town of Shura. The alluvium conceals most of the series, but the impression gained was that the greater part of the outcrop is limited to the lower horizons, consisting mostly of red clay. A little more sandstone occurs near Haudh, but although gravel and a conglomerate are seen on the surface of the plateau here, there is no certain evidence that the Conglomeratic stage of this series is actually present. Three miles west of Safinah some poorly exposed thin reddish-brown sandstone just pierces the alluvium. Similar sandstone occurs in the top of the Fars, as already mentioned; but since the beds in question are not apparently succeeded by any gypsum or limestone, they have been allotted to the Kurd series, and the boundary drawn along the upper part of the Haudh stream-course; this also fell into line with what appeared to be the same boundary separating Fars and red clays on the opposite bank of the river near Duwaisat Mansur. From Shura to Mosul none of the Kurd series was seen.

Mesopotamian Alluvium.—The gravel above Haudh belongs to the Mesopotamian Alluvium, which forms the usual plateau, and is argillaceous in character. It is pebbly around Hammam Ali.

New Alluvium.—The New Alluvium is pebbly north of Hammam Ali.

Structure.

The Mishrak anticlinal axis follows the sigmoidal curve of the highest points of the range, extending from Safinah, north-westwards to near Rassif, curving W.N.W'wards past Jahannam and swinging round past Kharrar to a direction a little north of west. The crest reaches its highest point near Tel Sulaiman, south-east of which it pitches, at first gently and finally with an abruptness not much less than 20°, beneath the alluvium at Hadra and Safinah. There appeared to be an outcrop of Fars beds, succeeded by red clays and sandstones to the south, on the opposite bank of the Tigris, showing that the fold persists across the river [1]; the bed of the latter is here characterised by rapids. N.N.W.'wards from the crest-maximum there appears to be a gentle pitch, but the north-eastern limb of the anticline north of Jahannam becomes involved in a vast rolling outcrop of Fars stretching right up to Mosul and far out to the west, with very gentle dips and numerous minor low undulations. It would be impossible to indicate these vagaries on a ½-inch map, even if it were more accurate than the one available (pl. 3), but the original anticlinal axis is dimly persistent through the high ground immediately south of Kharrar, when there may possibly be a slight rise of the crest.

With regard to the flanks, contrary to the rule hitherto observed, and perhaps as a result of the close proximity of a second anticline on the south-west, the north-eastern limb of the fold is, in a general way, steeper than the south-western. I say "in a general way," because there is considerable irregularity in the north-eastern limb and some undulation in the south-western. The map is on too small a scale to indicate these variations, but there are some quite pronounced plunges and recoveries on the part of the north-eastern limb, and in more than one spot a subsidiary anticlinal pucker. Where the anticline pitches, and indeed throughout the whole structure, the dip is never steady for any distance. Although dips of 30° and

[1] I have since learnt from Messrs. A. H. Noble and R. DuB. Evans that not only is this the case but that the Fars beds are here characterised by copious bitumen and a little oil.

more occur in the north-eastern limb, the general maximum dip is probably nearer 15° while that on the south-west is still less. The parallel anticline whose axis appears to be about 2½ miles south-west of the Mishrak axis is so low and flat as to be only just recognisable near Shura. North of Jahannam there seems to be a small flat northwardly pitching branch fold. From Kharrar north-eastwards the dip is, with few and unimportant interruptions, a north-easterly one as far as the alluvial plain in which Hammam Ali occurs, so that the oil and sulphur indications of the latter locality may be connected with the Mishrak fold, perhaps lying upon a subsidiary pucker in the flank of the main anticline. The area was a vast swamp of mud at the time of my visit, and a thorough examination was impossible. An extended survey with a large scale map and the drill will probably throw light on this area. As the seepages are of some importance the following remarks are offered for what they are worth. There is a minor line of anticlinal folding along the east bank of the Tigris, through Hawi Arslan and Humairah. There seems also to be a similar line along the west bank east of and parallel to the road between Hammam Ali and Mosul. This general line extends from Mosul perhaps as far south as Yuhainah, and would pass through Hammam Ali. My investigations were too brief and hurried for me to determine where along this line a boring would best be made, whether N.N.W of Hammam Ali in the Huslaun plain, or S.S.E. in the Yuhainah plain, whether on any of the small islands in the river here, or whether in any part of the hills between Lazzaka and Abu Sif. For about six miles west of Hammam Ali the general north-easterly or north-north-easterly dip persists, when a slight change commences, and two miles further west a distinct W.N.W.—E.S.E. anticlinal arch can be made out.

Petroleum and Sulphur.

Natural Indications.—One emanation of sulphuretted hydrogen was observed near Rassif. From the top of the cliffs a sulphur occurrence of importance was observed in a blocked branch of the Tigris immediately above the entrance of the Greater Zab. This forms a vast pool of sulphur-yellow water, the odour of sulphuretted hydrogen from which can be perceived throughout the Mishrak hills during an easterly wind. The Arabs reported that a poisonous gas is evolved therefrom which will overpower anyone unwary enough to approach too closely; this report is true, as the gas is

concentrated sulphuretted hydrogen (*see* p. 35). Bituminous earth is associated with this sulphurous emanation. As it seemed more than probable that oil indications must exist somewhere in the hills, my interpreter was sent on a long round, and after being shown two more sulphur localities was at length successful in obtaining information of a small seepage of tar, to which he was led by an Arab who had noticed it while out shooting, and of which he brought back samples; it lies on high ground in a stream-course a mile or so west of the large sulphur emanation in the River Tigris, and consists of a slow trickle of tarry oil, producing a small quantity of asphalt.[1]

At Hammam Ali there is a well-known spring of hot water, containing hydrogen sulphide and a little sulphur derived therefrom. This hot water is accompanied by traces of tarry oil, and there are conspicuous tarry pools in the immediate vicinity and also east of the spot where the Supply Depot used to be, some with gas rising. This bitumen has not collected in sufficient quantity for export, but it has been used locally for roofing and other purposes. The usual odour of sulphuretted hydrogen characterises these pools.

A small quantity of asphalt was found on the camping ground at Shura, but as the latter was a swamp of mud at the time, it was impossible to decide whether it had been brought there or was indigenous; I am inclined to think it was the latter.

A small sulphur-laden stream was noticed about six miles west of Hammam Ali.

Prospects of Boring.—The Mishrak anticline is a gentle one and, besides the conspicuous Hammam Ali occurrences, at least one seepage of oil is known. The chief risk of failure in sinking a boring is that the river, which has eaten well into the north-eastern limb, may conceal a fault or faults of magnitude. There is no evidence in favour of this, and I think the chances are against it. The prospects of obtaining oil are not unreasonable, and, in my opinion, warrant a test, which should be sunk a mile or so S.S.E. of Jahannam on the crest or 100—200 yards west of it. The rise in the neighbourhood of Kharrar and perhaps the country some distance west of Hammam Ali, may also be worth exploration, if the boring in the river area is successful. The parallel anticline

[1] Messrs. A. H. Noble and R. DuB. Evans subsequently found another oil seepage occurring at the junction of the valley in which the above recorded seepage was observed with the Tigris. For yet another seepage *see* note on page .

pitching towards Shura would, in the latter eventuality, be worth further investigation. The relationship of this and the Mishrak fold to that of the Jabal Kibritiyah, some distance further west, was not worked out; the latter signifies "Sulphur range," so that sulphur indications are evidently plentiful and oil seepages not improbable, though none of the latter were reported to me. If oil should be found in the Mishrak fold, the country from the river to the Jabal Kibritiyah and in and around the latter, and also the hills north of the Wadi-al-Adba, ought to be topographically surveyed on a 4 ins. to 1 mile scale, so that the geological structure may be worked out in detail, and the capabilities of some of the minor puckers and rolls estimated from an oil-winning point of view.

Sulphur.

The sulphur in the Tigris branch is described in Report No. 7.

Road-metal.

I was frequently asked by Sappers and Pioneers advice as to road-metal. As stated in a former report, the coarser varieties of the gravel of siliceous pebbles which so frequently borders the river, would furnish an excellent road-metal, provided it is broken into angular fragments. But since the difficulty regarding roads, between Sharqat and Mosul for instance and in many other places, is not so much to prevent wear and tear of the surface, but to prevent portions of the road subsiding or shifting bodily, I think broken angular fragments of limestone, which may be locally more plentiful than the gravel and is certainly more easily broken up, would do equally well. So long as the road is properly ditched and drained, limestone "metal" would probably serve the purpose as well as the harder chert and sandstone of the gravel pebbles. An experimental section of road made of limestone mixed with a little gypsum would be interesting. I have seen uncrushed gravel pebbles being used on the roads; this produces a very transient sort of structure, and seems scarcely worth the trouble of putting down.

12th January, 1919.

REPORT No. 6.—THE COUNTRY BETWEEN MOSUL AND QUWAIR ON THE GREATER ZAB, AND ITS PROSPECTS AS OIL-PRODUCING TERRITORY.

MAP.—$\frac{1}{2}$ inch=1 mile, Pl. 3.

MOSUL.

In the town of Mosul the gypsum of the Fars series is largely used as an ornamental stone, and is known as "marble" or "Mosul marble." Although it has no connection with marble, it is, when dressed and polished, remarkably like that stone, especially when streaked and veined with greyish impurities. It is, of course, softer than marble, and can be scratched with the finger-nail; nevertheless it is surprising how the stone keeps its shape, even when intricately carved, provided it is not subject to any but atmospheric abrasion. I have remarked before on the surprising resistance of gypsum *in situ* to the weather, and this quality is well exemplified in nearly every house of consequence in Mosul. For steps or staircases or any purpose involving mechanical wear it is unsuitable, but for window plinths, doorways, cornices, and especially for any internal decorative stone-work, it serves well enough where cheapness is a predominant consideration. It takes a fair polish, which, however, does not last very long.

GRAVEL.

The eastern half of the city of Nineveh contains a hard conglomerate, which has been mapped as the equivalent of the Alluvial Gravel. It has no appreciable dip, is comparatively low-lying, and newer-looking than that mapped as Pleistocene at Fathah, but there is very little difference in character between the two. It is seen in many places further south-east, overlying Fars beds at Hawi Arslan and near Salamiyah. Between Nimrud and Quwair it appears to be interbedded between alluvial silt, like the gravel described in former reports. Above Quwair its pebbles are of considerable size and are, therefore, admirably suitable for breaking up into road-metal. Fragments of silicified wood are not uncommon, and are in all probability derived from the sandstones of the Kurd series.

ANTICLINAL LINE IN THE FARS.

Southwards from Nineveh, Fars beds first make their appearance from beneath the alluvium near Kiz Fakrah, and from the Qarah

Quyunli stream-course a broad patch fringes the river as far as Salamiyah (*see* map, pl. 3). A small outcrop is seen two miles further on, and the oil occurrence south-east of Nimrud probably denotes a continuation of it beneath the alluvium. This long outcrop is probably continuous beneath the Tigris with that on the west bank of the river, but appears to constitute a minor line of anticlinal folding, the river occupying a shallow syncline of red clays and other soft beds belonging to the upper horizons of the Fars series. Some red sandstone in the stream-course at Salamiyah might possibly belong to the Kurd series.

Hawi Arslan Dome.

There is a distinct crest-maximum or dome-structure at Hawi Arslan, where limestone forms prominent hills. This limestone is succeeded eastwards by red clay as far as and beyond Yangijah. A fossiliferous limestone containing a radially ornamented oyster is seen in this red clay about a mile east of Hawi Arslan and again close to Yangijah, so that much, if not all, of the red clay belongs to the Fars. Whether the structure between the two occurrences is synclinal or anticlinal was not determined. If the former, at least some of the red clay between the two may belong to the Kurd series, but the beds are never far from horizontal, and there could only be a few feet at most of this series present. A little coarse sandstone was seen in the Fars, east of Qarah Quyunli. A little tarry oil exudes from two or three spots, with the usual accompaniment of sulphuretted hydrogen and sulphur, near the mouth of the small stream debouching at Hawi Arslan, so that this little dome or crest-maximum is worth testing. The horizon from which the oil seeps is very likely the same as that of Hammam Ali on the opposite bank of the river. The best place for a boring would be 300 yards north of the present village.

Humairah Dome.

There seems to be another gentler dome or crest-rise between Humairah-as-Sifla and Humairah-al-Uliyah, and since there are two small sulphur emanations near the former this might also be worth testing. A boring at Hawi Arslan should be put down first however.

The Nimrud (Calah) seepages.

Finally there are the seepages of tarry oil in the Shur Darah stream immediately south-east of Calah or Nimrud. I found flat cakes of asphalt inside the city of Nimrud in two places, but they may have been carried there. As no Tertiary rocks are exposed in this area, which is hidden beneath alluvium, it is difficult to locate a test-boring. As the Fars beds do occur to the N.N.W. and were not observed to the S.S.E., perhaps the former direction is the more promising, between Salamiyah and Nimrud. As will be seen from the map (pl. 3), there is a low dome of the Kurd series south-east of Nimrud, pitching towards that city, so that the seepages are more likely to belong to a dome partly inside the city or north-west of it. It seems desecration to suggest it but the city of Nimrud may not improbably form part of an oil-field of no small importance. Perhaps a more detailed and prolonged survey on a larger scale map might bring out data for guidance with respect to the Nimrud seepages which are fairly copious: there is the usual odour of hydrogen sulphide.

Nimrud (Calah).

Several dressed slabs still remain inside the walls of Nimrud, some carved with figures or scroll-work, others bearing inscriptions. Most of these blocks consist of gypsum, and in one case of alternating layers of gypsum and marly limestones. A figure of a man's head had suffered considerably from the weather, but the freshly exposed inscriptions were sharp and distinct. Dressed blocks of limestone, also from the Fars, are seen, and one of yellowish sandstone perhaps from the Kurd series.

Sulphur and bituminous earth at Judaidah.

Between the Monastery of Mar Behnam and the village of Judaidah is a small exposure of Fars rocks, succeeded southwards by sandstone belonging to the Kurd series dipping at 15° a little W. of S. This outcrop occurs on the top of a low hill about $\frac{3}{4}$ mile south and a little east of Judaidah. In the Fars is a small pool of water, eight or nine feet in diameter, in which hydrogen sulphide bubbles up in small quantity; a little of this becomes oxidised yielding free sulphur. Bituminous earth occurs round the bank of the pool. It is known as the "Leper's Pool" and is believed to be the spot which the Abbot of Shaikh Sharmatli struck with his staff in order

to produce the water in which he cured the girl martyr Sara of her leprosy and baptised both her and her brother Behnam. Although the exudation of hydrogen sulphide is small, the margin of the pool is three or four feet high and steep enough to enable the gas to concentrate on the surface of the water in still weather. Before the War, one of the monks of Behnam, while bathing in this pool, was rendered unconscious by the gas and was drowned; a second monk, in trying to extricate the body, also succumbed to its poisonous effect. There is a speculative chance of obtaining oil by boring near this area. As the structure is hidden beneath alluvium and I had not time to make an exhaustive search for other exposures, I am unable to advise respecting the most suitable spot for operations. Whether it is a small isolated dome with its centre occupying the summit of the hill, or whether it is part of a larger north-westwardly continuing anticlinal fold, is possibly determinable by exhaustive search with the aid of an accurate large-scale map. Its possibilities should be borne in mind while development proceeds elsewhere. The physical features, unimposing as they are, follow the normal N.W.—S.E. trend. There is a range known as the Qarah Tappah or Jabal Kharabat, extending N.W. to S.E. near the village of Kabarli. In the portion visited no Fars beds were exposed, the range consisting of an anticline of the Kurd series, with gentle dips in each flank, and pitching from near Kabarli very gently south-eastwards. The incipient root-like concretionary structure noticed in the sandstone on the north-west flank of the Jabal Hamrin, was well seen here. The south-western edge of this range is covered with gravel, but whether any of the Conglomeratic stage of the Kurd series is present, could not be determined. The $\frac{1}{2}$-inch map for geological work is inadequate in the extreme and unfortunately often misleading.

Mar Behnam.

The Monastery of Behnam contains some beautifully intricate scroll-work dating from the 4th century A.D., and carved on limestone, which I think better illumination will show to be carefully selected blocks from the Fars series. Gypsum is also used structurally and is occasionally ornamented, but delicate carving has been discriminately restricted to the harder limestone.

3rd February, 1919.

REPORT No. 7.—SULPHUR NEAR THE CONFLUENCE OF THE GREATER ZAB WITH THE TIGRIS.[1]

Sulphur near the Confluence of the Greater Zab with the Tigris.

This locality is alluded to in Report No. 5 on the Jabal Mishrak, from the top of which range it was observed that considerable quantities of sulphur had collected in a dammed branch of the Tigris below. A strong odour of sulphuretted hydrogen was at the same time noticeable, and when the wind blew from the east this smell was perceptible several miles west of the river. The locality is some 24 miles S.S.E. of Mosul, about $1\frac{1}{2}$ miles north of the confluence of the Greater Zab River with the Tigris, and $1\frac{1}{2}$ miles west of a village called Jaif (*see* map, pl. 3); one of the Arab names for it is "the Fountain of Hell." On visiting the spot it was found that the Tigris has deserted its eastern channel and confined itself to the channel west of the island. The eastern channel remains as a long sheet of water, which would have been completely shut off from the present river, were it not for a copious spring in the channel bed which feeds its northern end, and causes it to overflow southwards into the Tigris. This large spring gives origin to a stream of water winding through the sandy flat and flowing into the old Tigris channel. For forty or fifty yards along its course from its source, this stream is characterised by innumerable points of escape of sulphuretted hydrogen. The evolution of the gas is so brisk in places as to produce the appearance of ebullition, and it is dangerous to attempt to breathe below the top of the bank which is about five feet above the water. The odour above the bank is intensely strong and not to be endured for long; as already mentioned it can be smelt two or three miles away. Occasionally one momentarily catches the odour of tar, but this is usually completely drowned by the sulphuretted hydrogen. Bituminous earth occurs in the bank of the stream, and the Tertiary beds beneath the superficial deposits are obviously of Fars age. The water is warm and bitter to the taste. Further and further from the spring the oxidation of the hydrogen sulphide and liberation of free sulphur increase to such an extent that the southern end of the Tigris arm is a milky yellow pool. The sulphur, present as such, is, too disseminated to be capable of collection in any useful quantity,

[1] Published separately in *Rec. Geol. Surv. India.*, Vol. LI, p. 153.

but the amount of hydrogen sulphide evolved is very large. It is not a difficult matter to oxidise H_2S to SO_2 and ultimately to H_2SO_4, and I think the occurrence is worth the attention of a sulphuric acid expert. The supply may be variable, but the evolution has existed for some time and there is no reason why it should not persist for many more years. The risks and difficulties to be faced seem to be:—

(*i*) The Tigris may attempt to revert to its old course.
(*ii*) The supply may vary with the season of the year.
(*iii*) The supply may be altogether capricious.
(*iv*) The supply may be affected by any boring for oil in the immediate neighbourhood.

(*i*) could be controlled without much difficulty. With regard to (*iii*), the oldest inhabitants of a Kurdish village not far distant assert that the phenomenon has existed ever since they can remember and has been known for at least 100 years, so that the chances of the evolution continuing indefinitely are good, provided contingency No. (*iv*) does not interfere with it. The gas could be collected by building a gas-tight dome over the "live" area of the stream with a pipe leading off. Oxidation would soon destroy the smell.

Two or three types of sulphuretted hydrogen burners are in modern use for the manufacture of sulphuric acid, and all of them of simple structure. One consists of a brick chamber with "baffling-walls," into which the gas is admitted by a cast-iron pipe, the rate being controlled by an inlet valve. Air for the combustion of the gas is introduced partly by an annular aperture round the point of ingress of the cast-iron pipe, and partly by a separate regulatable aperture in the brick chamber. The heat produced is not only enough to prevent the flame of the burning sulphuretted hydrogen from being extinguished, but may also be used in concentrating the final product. The process is perfectly continuous and uniform and the consumption of nitre reduced in consequence. A different form of burner furnished with shelves is described by E. Lombard.[1] If a complete sulphuric acid plant is thought unfeasible in the present state of the country, large quantities of free sulphur could be obtained by burning the sulphuretted hydrogen in a limited supply of air, or by passing sulphur di-oxide into the stream. Sulphur di-oxide

[1] *Monit. Scient.*, 1889, p. 1231.

is easily obtained by burning sulphur in air, and reacts with hydrogen sulphide in the following way:—

$$2H_2S+SO_2=2H_2O+3S.$$

Some of the sulphur thus obtained could be burned to produce fresh supplies of sulphur di-oxide. There is no doubt that large quantities of sulphur are obtainable in this way, the final product being collected in a system of settling tanks with controlled inlets and outlets. With a properly constructed apparatus such as that used by Simpson and Parnell, a still greater yield of sulphur would be possible.[1] At present the sulphur precipitated is only a very small fraction of the hydrogen sulphide evolved.

The utilization of hydrogen sulphide is a problem well worth consideration in Mesopotamia, as the gas will probably be evolved in vast quantities from any oil wells that may be obtained. There will probably be an almost unlimited source of sulphur for anyone who can devise a simple contrivance for oxidising H_2S as it issues from oil wells and seepages.

3rd February, 1919.

REPORT No. 8.—PROSPECTS OF OBTAINING OIL IN THE QUWAIR DOME.

MAPS.—$\frac{1}{2}$ inch = 1 mile. Pl. 4.

INTRODUCTION.

Quwair is a Gendarmerie Post on the left bank of the Greater Zab—not on the right bank as shown on the old map—some eight miles from the confluence of this river with the Tigris. A range of low hills rises south-east of the town and extends between two large stream-courses for three or four miles in the same direction, where it sinks into a rolling upland as far as the Avanagh Dagh. This range coincides with a clearly defined anticlinal dome exposing Fars beds for a length of about three miles and a width of just under a mile. The general direction of the fold, which is a moderately gentle one, is W.N.W.—E.S.E. Exposures are good, but the map is of very little assistance.

ROCKS.

Fars beds are succeeded in the usual way by the red clays and sandstones of the Kurd series, and both are very little obscured

[1] G. Lunge; "Sulphuric Acid and Alkali," 3rd Edit., Vol. I, p. 370.

by alluvium except in the immediate neighbourhood of the river.

Fars series.—Gypsum, limestone and clays of the usual kind are present.

Kurd series.—The Kurd series also consists of the usual red clays and reddish brown sandstones, the latter occurring a little earlier than usual. Some six or seven miles from the Zab River, down the pitch of the fold, a series of gravel-covered hills is seen, commencing close to one of the villages called Tel-al-Khaimah, which did not appear to correspond with the village of that name on the map, but rather with 'Kiotek' [1]; it is possible these gravelly hills consist of the Conglomeratic stage of the Kurd series (*see* report on the Jabal Hamrin, p. 20), and they have been tentatively so coloured on the map, but no clear sections were observed. These gravelly mounds extend E.S.E'wards for two or three miles when sandstones and red clays reappear, partly concealed by alluvium. Northwards also of the Quwair dome between Mar Behnam and the Turkish road, is a gravelly range trending N.W.—S.E., which may also consist of this Conglomeratic stage; no sections could be obtained.

Mesopotamian Alluvium.—The Mesopotamian Alluvium conceals the Tertiaries along most of the river bank except on the edge of the river itself, where Fars beds just break through and seep oil. This alluvium includes gravel and conglomerate close to the river, especially along the north bank where the conglomerate is tough and forms prominent cliffs.

New Alluvium.—New Alluvium conceals any Fars exposure there might be on the north-west bank of the river.

Structure.

The dome can be traced across to the north-west bank of the River Zab, where it pitches very gently in a north-west direction along the old Turkish road (*see* map, pl. 4). Scarps of the Kurd red clays and sandstones are here exposed, the dip-slope being obscured by alluvium. Separated from this dome by a very shallow syncline, there appears to be another dome or anticline south-west of the road. No Fars beds are visible on this side of the river within the Quwair dome area.

[1] Neither Kiotek nor Kirapat appeared to be known to the local farmers and wayfarers whom we asked.

On the south-eastern side the dome rises distinctly to a point about 1½ miles from Quwair, close to a Survey cairn beside the road. As far as could be made out the Fars passes up under a transverse tongue of the Kurd beds, which stretches between the two lateral outcrops of the latter series. Near the cairn the crest is not simple but consists of two minor parallel crests which extend almost horizontally for about 1,000 yards in a S.S.E. direction to another point also close to the road, beyond which the anticline pitches distinctly towards the E.S.E. There may be a slight sag between the two points mentioned, but if so, it is hardly perceptible. The fold, therefore, is not straight but curves sigmoidally to a slight extent. The general maximum dip on the north-eastern flank is between 15° and 20°, but the dip waves and there are distinct minor puckers of some sharpness. On the south-west the general maximum dip is about 40° though similar waving produces locally higher and lower dips; at the junction between the Fars and the Kurd series it is 25°. The dome, therefore, is somewhat asymmetric, and follows the normal rule in being steeper on the south-west than on the north-east. The pitch E.S.E'wards is moderate, but very distinct.

Petroleum.

Natural Occurrences.—There are seepages of black tarry oil from several spots along 60 or 70 yards of the river bank at Quwair town. Around them artificial basins have been constructed, from which oil is extracted. These basins contain water in which a little sulphur has collected, and from which the usual odour of sulphuretted hydrogen emanates. The oil is probably derived from a seeping limestone whose outcrop is just covered by the gravelly alluvium; there is very little gas. This is another case of seepages occurring down the pitch of an anticline, exposed by a river.

Prospects of Boring.—The structure, nature of the seepages, age of the rocks exposed, and topographical position with respect to other oil indications, are all favourable factors. The chances of this being a field of considerable value are, in my opinion, distinctly good. If it should justify its promising appearance, it will be a well-defined field about half a mile wide and two miles long. The best location for a test well is 250 yards south of the Survey cairn mentioned on the line running along the middle of the crestal area. The second crest-maximum mentioned is 25° E. of S. from the cairn and about three-quarter mile distant from it, about half a mile due

west of the village of Jaria (not marked on the map), and 75 yards or so from the present telegraph line; this point and indeed the intervening tract between it and the cairn, are probably not much inferior to the first location. The irregularities in the crest and flanks cannot be of any serious economic importance, and it is doubtful whether they persist to any depth; some slight allowance for them may be found necessary as development proceeds, but at present they may be ignored. Oil is a capricious mineral, but, until proved otherwise, this small area should be treated as one of value and importance. There is a good road up to the location selected, and along the crestal area; water for the engine is of course available from the River Zab.

6th February, 1919.

REPORT No. 9.—OIL IN THE KIRKUK ANTICLINE.

MAPS.—1 inch = 1 mile. Pl. 5.
½ inch = 1 mile. Pl. 4.

INTRODUCTION.

Since one flank of this anticline is almost entirely concealed beneath the Alluvium and anything in the nature of an arch or anticlinal crest is seen in a few places only, the precise condition of the fold is largely a matter of speculation. A long narrow outcrop of Fars beds extends in a general N.W.—S.E. direction through the eastern outskirts of the town of Kirkuk. North-westwards it reaches the village of Amshahr, beyond which an outcrop of Fars beds along the same line of folding reaches and probably crosses the Lesser Zab; south-eastwards the outcrop was traced as far as the latitude of Panj Ali. The dip with few exceptions is north-easterly and from moderate to steep. On the north-east the outcrop is succeeded in a normal way by the Lower stage of the Kurd series and this in turn by the Upper or Conglomeratic stage; to the south-west the succession is obscured by Alluvium except in two or three places. The clearest section is seen east of Panj Ali, where the Fars is succeeded on both sides by red clays belonging to the lowest horizons of the Kurd series. The structure is here seen to be that of an isocline overfolded towards the south-west. North-west of this area the anticlinal nature of the outcrop is surmised rather than proved. The

tightness of the folding coincides with a closer proximity to the origin of the folding movement, which proceeded from the north-east.

Rocks.

Fars series.—The Fars consists of the usual sequence of gypsum, limestone and clays. Amongst the limestones is the noticeable pelecypod bed, an old shell-bank crowded with small pelecypods, and having a superficial resemblance to a nummulitic limestone. Bright red clays are especially prominent in the neighbourhood of Kirkuk. The uppermost bed is sometimes a gypsum band, sometimes a fossiliferous limestone; a little below is a thin layer of reddish sandstone similar to that of the succeeding series.

Kurd series.—The Lower stage of the Kurd series consists of the usual red clays and current-bedded sandstones, the former predominating near the base and producing flatter and more rounded topography, the latter increasing upwards and producing the series of characteristic ridges indicated on the map. Thick beds of light reddish clay again appear in this stage, however, as it passes up into the Upper or Conglomerate stage. In the latter pinkish or yellowish red clays are prominent, the colour being less intense than that of the earlier argillaceous deposits. The boundary line between the two stages was taken as the base of the first thick conglomerate, which produces outstanding physical features in the form of a line of loftier round-topped ridges. It is an artificial boundary since thin inconstant conglomerates occur below it, but it has been selected as being easy to identify and map. Deposition has been uninterrupted from the Lower to the Upper stage. The most prominent conglomerate forms a curiously regular even range, extending with scarcely a break for a great many miles, and providing many streams of excellent water on both sides, at any rate during the winter months. As the map shows, the Lesser Zab and the Qarah Chai are the only two streams which pierce the part of this range under description, which is known variously as the Shamasin Dagh, the Baba Gurgur, and the Jabal Buar. Its sky-line is a monotonous, almost unbroken, slightly denticulate line, and its dip-slope presents such a characteristic appearance of intricate dissection combined with rounded outlines—due to the easy disintegration of the conglomerates and the soft, interbedded clay bands—as to be recognizable many miles distant. North-eastwards it is covered by high-lying Alluvium.

The thickness of the Lower stage opposite Panj Ali, works out at over 7,000 feet. The thickness of the whole series must be over 12,000 feet, a river deposit rivalling in size as it resembles in character and age, the great Siwalik deposit of India.

Mesopotamian Alluvium.—As in former maps the boundary of the Alluvium indicated is merely the approximate limit of Tertiary exposures, and has no tectonic significance.

Structure.

It will be advisable to consider first the Panj Ali area in the extreme south, where the structure is clearer, and proceed thence north-westwards, examining these more obscure portions in the light of the more complete succession in the south-east (*see* map, pl. 5).

In the Panj Ali area, reviewing the section from north-east to south-west, the Conglomeratic stage on the north-eastern flank of the anticline passes down into the Lower stage of the Kurd series dipping at angles varying between 40° and 50°; approaching the Fars, however, the dip diminishes gradually to 35° and 30°, and then rapidly steepens to 50° and 60°. The dip along the north-eastern fringe of the Fars outcrop is here about 60°; this is followed by minor puckering and contortion, but a distinct arch of rather more importance than those of the puckers can be made out along the centre of the outcrop, and, from all appearances, may be accepted as the crest of the main anticline. Further to the south-west vertical dips and further contortion follow, until the boundary between the Fars and the Kurd series is reached. Here the dip in both is 25° in an E.N.E. direction, showing considerable reversal; the junction appears normal, the beds of the newer series consisting of the red clays characteristic of the lowest horizons. We have here, therefore, a tight, compressed, overfolded, contorted isocline, the overfolding being in the direction of the folding movement, *i.e.*, to the south-west. Small slips and faults are seen in the south-western limb where small minor wrinkles have given way under the compressional strain. I have tried to illustrate in a somewhat diagrammatic way the type of fold in sketch-section B-B (pl. 5).

Proceeding north-westwards from the Panj Ali area, we find the arch of the crest disappears, and judging from the narrowing outcrop and sinking topography, the fold pitches. Two miles south-east of Kirkuk it commences to rise again, but the dips are all north-easterly and the Fars outcrop is invaded by the Alluvium.

At Shorau is a small exposure of sandstone dipping south-west, succeeding vertical and contorted Fars beds.

At the oil locality the anticline seems to be a little more open. In a traverse from north-east to south-west the dip in the Lower stage of the Kurd series is again seen to diminish from 50° to 25° towards the Fars outcrop, but to steepen abruptly immediately above the latter series. Dips of 50° and 45° characterize the north-eastern limb of the Fars, and a distinct arching over of the beds takes place immediately north-west of the oil seepages, followed by south-westerly dips of 28° and 45°, after which everything is concealed by Alluvium. This arch is fairly acute and rises and pitches rapidly producing a succession of small dome-areas, three at least of which can be distinguished north of the oil occurrences. Very little of the south-western limb is to be seen, but it seems probable that the arch described is the crest of the main anticline. Presumably steep and probably reversed dips succeed the visible south-westerly dips beneath the Alluvium, but the fold is evidently not quite so tightly pinched as it is to the south-east and the structure a little more favourable for the storage of oil.

North-westwards beyond the series of domes the south-western limb is perhaps represented by vertical beds, but no certain crest can be seen until the fold pitches at Amshahr; here westerly and south-westerly dips are observable and beds can be seen swinging round from one flank to the other. Before Amshahr is reached, the anticline curves round from a N.W.—S.E. direction towards the W.N.W., then again N.W. to Qush Qair, and again W.N.W. to Amshahr. At Qush Qair the narrow belt of Fars is succeeded on the south-west by almost horizontal red clays and sandstones, so that the anticline is here very compressed and perhaps fold-faulted at the boundary between the two series of rocks, the general dip in the Fars being vertical or steep.

Petroleum.

Natural Occurrences.—The oil seepages, which are very ancient, occur some 5 miles north-west of Kirkuk, and are exploited by an Arab who is said to get 48 kerosene tins full of oil per day. Many pits have been dug, some 15 to 20 feet deep, some much smaller, and the black tarry oil is skimmed off the surface of the water which collects in them. There is the usual accompaniment of sulphuretted hydrogen and a small deposition of sulphur. South of the stream

which here breaks through the hills, tarry bitumen and bituminous earth are seen along the road and on the banks of the stream, these and the exploited oil seepages north-west of the stream occurring close to the line of the anticlinal crest and a little north-east of it.

South-east of the stream and north-east of where the crest line should be, is an oval patch of flat bare ground, evidently once a shallow pool, from which emanates sulphuretted hydrogen in considerable quantity. This gas has been at some time ignited—probably artificially as I doubt whether there is any spontaneously ignitable constituent—and perpetual fires now burn there. The rocks beneath have probably become so hot, that it would be difficult to extinguish the flames in the ordinary way. I visited the spot the morning after a violent storm of wind and rain, and found the fires unextinguished. Whether there are traces of phosphoretted hydrogen or some other spontaneously combustible constituent or not, the bulk of the gas is sulphuretted hydrogen and the product of its combustion sulphur dioxide. It cannot be used as an illuminant for two reasons. In the first place the flame has scarcely any illuminating power, and secondly, the fumes of sulphur dioxide would be overpowering. The first difficulty, of course, could be remedied by using incandescent mantles, but the second is decisive enough. For the same reason the gas could not be used for cooking purposes except by some special contrivance. But it might be used as a source of sulphur. I have already suggested such a use for the same gas at the confluence of the Greater Zab and Tigris, and it would, I think, be possible to develop the Kirkuk gas occurrences in a similar way though on a much smaller scale, provided no one can be persuaded to bore for oil in this area. This proviso is made since boring would probably commence within 1½ miles of the gas-evolution, and might possibly affect the gas-supply. If not thus interfered with, the supply for all practical purposes may be looked upon as perpetual.

There are two or three other similar bare patches in the immediate neighbourhood and also north-west of the stream, some of which smell faintly of sulphuretted hydrogen, and most of which contain slightly bituminous earth.

Prospects of Boring.—The seepages are of some importance and the constant evolution of sulphuretted hydrogen is not an unfavourable sign. On the other hand the structure is not ideal, and it will be my endeavour to point out as succinctly and impar-

tially as possible the risks that will have to be taken by anyone undertaking boring operations in this area. Assuming that the small domes described north-west of the seepages are actual parts of the main anticlinal crest, the chances are not unfavourable that the latter is, for the length of at least a mile, sufficiently intact to have conserved any oil-pools that may exist below; the copiousness of the seepages also pre-dispose one to infer that these oil pools may be remunerative, though probably not excessively so. The principal risks to be faced arise from two factors: (i) our ignorance of the nature of the south-western limb of the anticline and therefore of its degree of asymmetry; and (ii) the depth at which remunerative oil horizons might occur. A small sketch will best illustrate how these factors affect the question.

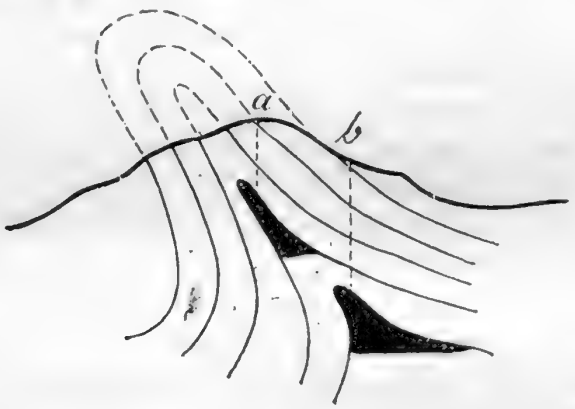

FIG. 1.

Supposing the fold to be of the shape shown in figure 1, in which two oil-pools are indicated in black. Then it is obvious that a boring sunk on the superficial crest would miss entirely the oil-pools. To reach the higher of the two the boring would have to be sunk somewhere in the immediate neighbourhood of a point *a* at a certain distance from the superficial crest, whereas to reach the lower the boring would have to be located still further in the same direction from the superficial crest at a point *b*.[1] That the south-western limb is steep or reversed is probable from what we know of the fold elsewhere, but to what extent it is overfolded at this particular spot we do not know. Nor do we know the depths at which the oil-pools—if they exist—occur So that the difficulty is to gauge the correct distance north-east

[1] *See* ***Rec. Geol. Sur. Ind.***, Vol. XXXIV, p. 253.

of the surface crest at which to bore. It might require one or two trials along a N.E.—S.W. line across one of the domes, before the correct "lie" of the pool is found, but I should be inclined to commence, say 50 yards north-east of a small stone cairn I built about half a mile north-west of the stream above which the seepages occur. This cairn is situated on the north-eastern flank of a low hill forming one amongst the first line of hills overlooking the plain, and constituting one of the small domes mentioned. The prospects and risks may, I think, be summarised as follows :—

(*i*) That the chances of striking remunerative oil-pools are not remote.

(*ii*) That these pools will not be excessively large, and that the yield, if substantial at the beginning, will decline rapidly.

(*iii*) That the field will be very narrow, and that there will be danger of wasting any profits made in proving its width.

(*iv*) That the prospects of the field extending either south-east of the stream, or more than about a mile north-west of it, are unknown.

(*v*) That it will probably not be possible to tap more than one or two horizons by a single boring, it being necessary to commence a new boring further from the surface crest in order to reach deeper pools.

(*vi*) Difficulty in keeping the hole straight is to be expected in drilling.

Any company exploiting this area should employ expert advice during their operations and must be prepared to face indifferent success or failure.

26th February, 1919.

REPORT No. 10.—NOTES ON THE GEOLOGY OF THE COUNTRY BETWEEN TAZAH KHURMATU AND TÄUQ.

MAPS.—1 inch = 1 mile. Pl. 6.

TAZAH KHURMATU AREA.

Very bad weather and the consequent death of two camels delayed work in this area. East of Tazah Khurmatu an anticline pitching gently in a N.N.W. direction is seen, exposing the Kurd series only. Both Upper and Lower stages are present and the

boundary line between them, which is somewhat difficult to fix, has been drawn swinging round a little short of the Täuqmaqil Chai. The Lower stage consists of the usual sandstones and clays of the middle horizons and the light brown clays characterising the highest horizons. The latter pass up into the Upper stage which contains the usual soft conglomerates, and thick brown clays. The same thick conglomerate, noticed in other areas (Nasaz zone) produces a similar long, monotonous, level range of hills in this case known as the Matarah Dagh. North of Tazah this conglomerate swings round in a horseshoe, forming the Sareh Tappah. Further north on the other side of the Qazah Chai we find some of the youngest Tertiary beds hitherto met with. They form part of the Conglomerate stage, consisting of light brown or pinkish clays with thin infrequent conglomerates or gravels, and occasional layers of current-bedded sand-rock.

Täuq Area.

South-eastwards the anticline becomes overfolded, and north-east of Täuq fold-faulted. In this interesting area, south of Täuq Bridge, a traverse from north-east to south-west shows the following sequence. The Lower stage of the Kurd series is present in a normal way, its middle horizons consisting of the usual rapid alternations of massive sandstones and clay bands, producing the characteristic system of parallel ridges and valleys; these pass down into the lower horizons consisting of thick masses of red clay which, however, produce more prominent topography than usual on account of the presence in them of numerous thin layers of more sandy material, both clay and sandstone being deeply iron-stained. These beds overlie gypsum, limestone, and clay bands of the Fars, dipping at the same angle, *viz.*, 30° in a north-west direction. At its south-western boundary, however, the Fars is not in contact with these red clays and thin sandy partings, but with the massive sandstone bands belonging to the middle horizons of the Lower stage of the Kurd series. The lower horizons are missing and the boundary is a reversed fault. The reversed dip in these massive sandstones rapidly steepens till the beds become vertical, and then dip south-westwards in the normal direction at angles which rapidly decrease. A few thin gravel partings are seen in these sandstones just before they pass up into the light brown clay zone; the latter, in turn, passes up into the Conglomeratic stage, forming the low mound-

like hills south-east of Chavirgah. The reversed fault soon becomes hidden by alluvium to the south-east. North of the Täuq Chai, the outcrop of the Fars continues for about half a mile and then ceases; its dip is generally 26° in a north-east direction, but the river section shows there is some contortion. At the extremity of the outcrop, owing to the intervening fault, there is no swinging round of the Kurd beds from one flank to the other, as there would be in a normal pitching anticline. Here also the lower horizons of the Kurd series are missing on the south-west and the Conglomeratic stage approaches still nearer the Fars. There are no clear sections in this Conglomeratic stage, but, from the shape of the hills and the distribution of gravel over their tops, the boundary line has been drawn as indicated; the western part of the hills consists, as would be expected, of massive light brown clay. The fault, therefore, probably extends for some distance north-westwards, the displacement or thrust apparently being greater north of the Täuq Chai than to the south. The low mound-like hills of the Conglomerate stage south of Chavirgah curve curiously towards the S.S.W., but I came across no sections showing to what this is due.

11th March, 1919.

REPORT No. 11.—OIL IN THE NAFT DAGH OR JABAL KARACH BETWEEN TUZ KHURMATU AND KIFRI.

MAPS.—1 inch = 1 mile. Pl. 8, with three sections.

INTRODUCTION.

The area under report commences at the Quru Chai and embraces the hilly ground between this and Kifri (Sallahiyah). In the north-west this hilly ground forms a belt between two plains, but south-eastwards the northerly plain ceases and the hilly tract becomes continuous with that of Kani Qadir to the north. Many of the footpaths marked on the map have fallen into disuse or do not exist, and progress across the hills is most wearisome. An attempt has been made to differentiate on the map the five phases or zones of the Kurd series. These boundaries are by no means well-defined; in places they are frankly impossible to identify and have been drawn partly by interpolation between areas where the division is more recognisable. In spite of this, in the great majority of traverses, they express an actual though gradual change from one zone to the other.

The Naft Dagh and its continuation the Karach Dagh form the core of a N.W.—S.E. sinuous anticline, overfolded towards the south-west, and, at least in places, fold-faulted. Furthermore it is not a simple fold, but is contorted in varying degrees. It is tightly isoclinal, and actual crests either of the parent anticline or of its minor puckers are very seldom visible. Most of the contortion in the vicinity of the Palkanah oil pits can be followed; some idea of it is given in the sketch sections.

Rocks.

The rocks consist of a core of Fars beds comprising the usual bands of gypsum, limestone, and green and red clays, succeeded by the red clays and sandstones of the Kurd series. The rocks of the latter series have been described in former reports and can be divided into 4 or 5 more or less distinct phases or zones, each one passing gradually up into the other. The lowest three zones form what I have alluded to as the Lower stage of the series. In the Upper or Conglomeratic stage two phases can, I think, be recognized and there may be higher zones not yet seen. The beds may be tabulated thus :—

Kurd series—

Upper (Conglomeratic) stage	Zone c. Zone d.
Lower stage	Zone c. Zone b. Zone a.

Zone "a" is characterised by abundance of red clay with comparatively few sandstone bands, which are thinner, more argillaceous and therefore finer in texture, and more deeply iron-stained than those of the succeeding zone. These characteristics are not always simultaneously present. Sometimes sandstone is almost as plentiful as it is in the "b" zone, but the bands are less massive and redder in colour (as in the Aq Su section), or they consist of numerous thin iron-stained bands with a considerable proportion of argillaceous material. This zone coincides with a belt of lower-lying and less rugged country between the range of the Fars outcrop on the one hand and the series of sandstone ridges forming zone "b" on the other; it is usually occupied by a large, open, winding, longitudinal, compound valley. Thin layers of selenite derived from the Fars gypsum, and often a thin layer of marl are found among the

lowest horizons of this zone. Between the Kurah Chai and Kifri no distinction between zones "a" and "b" can be recognized.

Zone "b" is characterised by many thick massive sandstone bands, which, if they do not actually preponderate in bulk over the inter-bedded clays, are of more importance than they are elsewhere. The sandstone or sand-rock is soft, moderately friable, light-coloured, frequently current-bedded, and sometimes full of root-like concretions; it is coarser and less argillaceous than that in zone "a." The bands increase in thickness towards the middle of the zone; towards the top the separating clays become thicker and thicker, and assume the light brown colour so typical of the next zone, while the sandstones become pebbly and contain thin inter-bedded layers of conglomerate. This zone forms a belt of high-lying country between the two lower-lying belts of "a" and "c"; it produces rugged topography consisting of ridge after ridge rapidly alternating with deep, narrow, straight, simple valleys.

Zone "c" consists of very light brown clay with very few sandstone bands. The latter increase towards the base as the zone passes down into "b." The sandstones usually contain strings of pebbles, and thin inconstant conglomerates are seen in them and separating the clays. This zone forms a comparatively low belt between the sandstone ridges of "b" and the round-featured range of zone "d." Where the dip is low, open, gently-sloped country is produced, but where the dip is steep, as on the Aq Su, there results a bewildering assemblage of steep conical hills, which are almost as difficult to traverse as the sandstone ridges of "b." The colour of the clay—an extremely pale brown—is very characteristic and differs from the red of the zone "a" clays.

Zone "d" is typified especially by a thick somewhat loose conglomerate, which caps a long, regular, level, uninterrupted range of hills, low or high according to the thickness of the conglomerate, its dip and other factors. The conglomerate usually contains sandy partings, and overlies light brown clay over which it has spilled its pebbles, producing intricately dissected topography of which all the details are so rounded off and deprived of sharp angles, that the zone can usually be identified from a long distance. Streams of good water originate from it and the slopes of the range are typically more grassy than others. Other conglomerates occur in the zone, sandstone is poorly represented, and light brown clay predominates in actual bulk. As will be seen, this zone is strikingly developed

in the Jabal Nasaz ten or eleven miles to the north-east, for which reason the name "Nasaz zone" is proposed for it (*see* p. 58).

Above the conglomerate forming the range just described, come thick masses of light brown clay with a few thin conglomerates and sandstones. This zone—zone "e"— is indistinguishable from zone "c" except by its position. It forms slightly undulating plains.

Pleistocene.—On the south-eastern side of the Kifri gorge is a horizontal conglomerate lying unconformably upon the contorted Fars rocks, well up above the alluvial plain. It has been classed as Pleistocene and is probably equivalent to that seen at Fathah.

Structure.

As it is desirable that anyone anxious to prospect this area for oil, should form his own conclusions as precisely as the evidence admits, as to the risks he has to face in searching for undisturbed oil-pools below, the structure of the anticline will be discussed section by section from north-west to south-east.

The Fars beds first make their appearance from beneath the alluvium north of Albu Sabah (*see* pl. 8); they are here of very small thickness and practically vertical, so that the fold is steep and tight from the commencement of the outcrop. Due east of Albu Sabah the anticline is seen to rise towards the south-east in two or three rapid jerks. Traced in the same direction the general north-easterly dip sinks to 45°, 30° and 20° in places, being steeper along the north-eastern than along the south-western Fars boundary. This, we shall see, is a very constant character all the way along the outcrop, *viz.*, steep or steeply reversed dips along the north-eastern boundary, and gentle still more reversed dips along the south-western boundary—reversed in the opposite direction of course from those in the north-eastern limb. In other words both limbs of the anticline tend to become or do become, reversed, the south-western limb much more than the north-eastern. North of Tuz Khurmatu, sandstones belonging to zone "b" of the Kurd series are seen in contact with the Fars along its south-western boundary, dipping at about 20° in a north-eastern direction; this boundary is, therefore, a reversed fault. Evidence of this fold-fault is again seen west of Kifri where the conglomeratic zone "d" is found within a mile of the Fars outcrop, dipping gently. North of Tuz Khurmatu the fold seems to be something of the nature of section 1 on plate 8.

Traces of arches or crests can be made out along the south-western face of the hills in one or two spots, but there is much contortion.

Sections 2 and 3 on plate 8 will give some idea of the shape of the fold in the neighbourhood of the oil wells at Palkanah opposite Sulaiman Beg. These wells are situated along the line of a small subsidiary anticline occurring in the north-eastern flank of the main fold. This small fold, like the main anticline is isoclinal and itself slightly contorted; near the wells it has been bent bodily backwards by its contact with the similarly bent main fold in the way depicted. Extending parallel to the line of wells and a few yards north-east of them is a double ridge of limestone with a local strike of 55° W. of N.—55° E of S. and a dip E.N.E. of 50-60°, which probably represents the core of this fold. This limestone is flanked on both sides by white gypsum succeeded by red and green clays belonging to the uppermost horizons of the Fars. To the south-west these red and green clays form a small syncline, along which flows a straight N.W.—S.E. reach of the stream, and which separates the subsidiary from the main anticline, which is contorted in a way similiar to that sketched. This interesting minor anticline can be traced for two miles or so to the north-west, the limestone and gypsum pitching underneath the red and green clays, and showing the remains of an acute arch. When traced south-eastwards the minor anticline is no longer recognisable after 1½ miles; in pitching it loses the bent backwards and assumes a normal overfolded condition as shown in the 3rd section plate 8. The small syncline, when traced in the same direction, widens, and includes thin sandstones which are referable to the lowest horizons of the Kurd series; it also becomes normally underfolded in correspondence with the anticline.

Leaving the oil-well locality and proceeding south-eastwards we find the same baffling persistent gentle north-easterly dip in the outward face of the hills, with here and there contortion, but no definite relics of a crest. Between the sulphur spring of Gharrah and the Kurah Chai the Fars outcrop becomes very narrow and the beds along the alluvial boundary are almost horizontal.

In the Kurd series forming the north-eastern limb considerable variation in dip may take place along the strike, causing a widening or narrowing of the outcrop of its zones; north-east of Palkanah a small subsidiary anticline can be seen. As in other areas, we find the same curiously rapid erection of the beds on approaching the

Fars boundary. Take the section opposite Albu Sabah from north-east to south-west (*see* map, pl. 7). In the Conglomeratic stage the north-easterly dip is quite gentle. Passing down into zone " c " it averages about 40°. In zone " b " there is a gradual drop from 45° to about 15.° In zone " a " it sinks as low as 10°, but within 200 yards of the Fars boundary it has risen to 30° and at the boundary is 40°, while a little way inside the boundary it becomes 75°. There are more causes than one which may have individually or collectively been responsible for this ridging up of the Fars outcrop. The primary cause is no doubt the resistance to the thrust, but the localization of this erection may have been to some extent also due to (*i*) the great plasticity of wet gypsum sediments, (*ii*) a premature folding movement before or during the deposition of the Kurd series, especially of its lowest zones, (*iii*) denudation accompanying a folding movement and lightening the burden over the anticlinal crest.

Besides the main reversed fault along the south-western Fars boundary, other reversed strike faults are not uncommon within the Fars outcrop. Some of these can be well seen in the sections of the Aq Su and the Kifri stream.

Petroleum.

Natural Indications.—Due east of Tuz Khurmatu, close to one of the places where an arching over of strata was observed, is an emanation of hydrogen sulphide in a small stream; the actual source of the gas was not found, but it is probably associated with the usual bituminous earth. Some 2½ miles further down, also near a crestal structure, is another occurrence of the same kind (*see* map, pl. 8).

The locality of Palkanah (Abu Sarkal) opposite Sulaiman Beg, and commonly spoken of as the Tuz Khurmatu oil locality, has been known for a long time. The so-called wells are large pits dug presumably upon natural seepages, and lying upon a line very close to, and, as I have observed, probably a few yards south-west of the axial plain of an isoclinal subsidiary fold occurring in the north-eastern flank of the main anticline. The oil is the usual black tarry material smelling of sulphuretted hydrogen and accompanied by sulphur-laden water. It has already been reported on by the Anglo-Persian Oil Company's chemists. At present some 14 pits are being worked, yielding between 240 and 280 gallons of crude oil a day, one well producing more than the other thirteen. It is carried on the

backs of donkeys and mules to Tuz Khurmatu where it is subjected to a crude distillation in 5 or 6 stills, each consisting of a retort and spiral condenser. The two extreme wells on the line are a little under a mile apart, but further south-east there is a little bituminous gypsum in one spot and in another an emanation of sulphuretted hydrogen accompanied by bituminous earth. Oil indications are by no means confined to the subsidiary fold, but are found in the main anticline, where outcropping bands of gypsum and limestone are seen to be bituminous for many yards in the south-western face of the hills in the vicinity of the gorge.

Some three miles north-west of the Kurah Chai, in the uppermost horizons of the north-eastern limb of the Fars, is the sulphur spring of Gharrah. This is an emanation of sulphuretted hydrogen accompanied as usual by bituminous earth. In the plain at the foot of the hills immediately opposite this spot, a long trench and a round pit have been dug, evidently on natural seepages, since they both contain tarry oil floating on water. There are a few unimportant bituminous beds outcropping between this spot and Gharrah.

The seepage in the hills opposite Oniki Imam, 8 or 9 miles E.S.E. of Kifri was not visited.

Prospects of Boring.—The prospects of obtaining oil by boring cannot be called attractive, but the steady yield from the pits at Palkanah, though very small, arouses the question whether something more could not be made of this and possibly other spots along the fold. The anticline is not only strongly overfolded and fold-faulted, but is a tightly compressed, considerably contorted isocline. Possibly other reversed strike faults—which are never easy to recognize—are more frequent than a preliminary survey would indicate: that they do exist is shown in the Kifri and Aq Su sections. We may at once disabuse our minds of any hope that this could ever prove a rich field. What I have said regarding the Kirkuk area applies still more disadvantageously to this anticline. The most that could be expected is a very narrow field with capricious oil pools tapped by rapidly declining wells. A remunerative well struck in such an area is sometimes more a curse than a blessing, as it raises false hope and leads to further expensive experiments.

In the absence of any undisturbed spot with favourable structure, one would be unwilling to locate any test boring far from the natural occurrences. In making a location for a deep bore I should be inclined to assume that the axial plane of the main anticline is a

little south-west of the summit of the range, and select a spot, therefore, north-east of the summit, so as to allow for a considerable hade of the axis locus. If it were necessary to prove one way or the other whether the area contained remunerative supplies of deep-lying oil, I should bore in the above position, first in the Palkanah area, secondly at Gharrah, and perhaps thirdly, between the two sulphuretted hydrogen occurrences east of Tuz Khurmatu. The result, as I have said, must be looked upon as entirely speculative.

A proposition less hazardous is the exploitation with shallow boring, especially of the minor anticline in the north-eastern flank at Palkanah. That the natural indications in this area occur on the overfolded side of the axis and not on the other side, is perhaps an adverse point, as this restriction is rather in favour of the seepages occurring along a strike fault. The undertaking would be speculative, but less expensive and therefore less hazardous. Borings should be located on the north-eastern side of the double limestone ridge, beginning at the highest point.

Lastly, there is the question of hand-dug wells or pits. I would suggest one or two experimental pits between some of the present pits, along the same line, to ascertain whether an actual surface seepage is necessary as an indication of oil below; there is room for such pits. I should also be inclined to suggest, provided that a shallow boring is not to be faced, that an experimental pit be sunk on the north-eastern side of the limestone to a depth of say 200—300 feet, piercing the steeply dipping limestone on the way. The Burmans reach depths of 400 feet in this way by using a diving apparatus, through which a supply of air is pumped down to the digger. Light is thrown down by a mirror at the surface, and the diggings are hauled to the surface in the usual way. Their shafts are four feet square, and timbered most of the way down. The difficulty would be getting through the limestone, but this could be engineered by judicious use of blasting powder. The Burmans get through hard bands by dropping a heavy weight from the mouth of the well; this, however, is a cumbrous, though sufficiently effective method, and might fail in the case of a highly-inclined band of limestone.[1]

Kifri "coal."—The Kifri "coal" mines are situated about 3 miles E.S.E. of Kifri in the upper half of zone "a" of the Lower stage of the Kurd series, some 1,100 feet above the top of the Fars gypsum

[1] *Mem. Geol. Surv. Ind.*, vol. XL, pt. 1, p. 76.

series. At the time of my visit the mines were, unfortunately, flooded with water and the deposits not properly visible. The occurrences *in situ* at the surface were very scanty and obscured; one of these occupied a locally contorted and faulted spot, and from the very meagre evidence one gathered that the mineral was extremely "pockety." It appears to be restricted to a length of not more than 800 yards along the strike. In one small stream-course I found a small mass of it, which might well have originated from an isolated tree-trunk. Much of the material seems to be of the nature of those curious and interesting carbo-petroleum minerals which pass under various names such as Torbanite, Albertite, Stellarite, Joadga, Kentucky Cannel Coal, Tasmanite, Manjak, etc., and which have properties intermediate between those of coal and petroleum. It evolves no bituminuous odour until burnt, and has the low calorific value of about 500. It contains 10·9—13 per cent. of ash, 30·7—39 per cent. of fixed carbon, 57·9—43 per cent. of volatile matter, and 0·5—5 per cent. of moisture....[1] The working of such deposits consists usually in taking what can be seen until it is too thin or impure to pay. From the use made of it by the Turks and from the number of buildings they erected round the mines, one would judge the deposits to be of comparative importance, especially in a country short of fuel. The dip of the strata at the mines is high; the beds twist a little locally, but the general dip is about 55° in a N.E. direction.

29th March, 1919.

REPORT No. 12.—THE PETROLEUM INDICATIONS OF KANI QADIR AND ITS NEIGHBOURHOOD, INCLUDING THOSE OF GIL.

MAPS.—1 inch = 1 mile. Pl. 7.

INTRODUCTION.

The Kani Qadir locality, some two marches north of Kifri, was at the time of my visit somewhat inaccessible owing to bad roads. I found it simplest to abandon my camp and camels and live in Kurdish villages during the 8 or 9 days spent on the traverse, taking a camp bed and bedding and a few tinned stores on two country donkeys. This area is, unfortunately, more interesting from an academic than an economic point of view. The oil occurrences lie along the north-eastern foot of the Jabal Nasaz. Little of a

[1] Analyses by the Railway Department, Baghdad, and by the Anglo-Persian Oil Co.

recognizable anticlinal structure remains, most of the south-western limb having been cut out by a large reversed fault along which the north-eastern limb and perhaps a small portion of the crest have been thrust up over more than a mile of strata. A narrow outcrop of Fars beds, striking N.W.—S.E. is thus brought into contact with the Upper or Conglomeratic stage of the Kurd series.

Rocks.

Fars series.—The Fars beds consist of a central core of limestone which, assuming the fault to be a fold-fault, probably represents a more or less fractured anticlinal crest. This core on the south-west is bounded by the reversed fault; on the north-east it is succeeded by a band of clay and sometimes a little gypsum, and then usually by another thin limestone band. Above this come the red clays and sandstones of the Kurd series.

Kurd series.—In the Kurd series the three zones of the Lower stage, described in the last report, can be dimly recognized at the northern end of the area. Here a soft belt of cultivated ground slopes down from the Fars outcrop to a north-westerly-flowing stream, and consists mostly of clay whose superficial colour is more brown than red owing to the silt spilt over it from the Conglomeratic stage of the Jabal Nasaz; this constitutes zone "a." North-east of the stream sandstones become a little more frequent, and produce gradually rising ground as far as a low watershed, but there is still much red clay present. Beyond the watershed brown clays of zone "c" become thicker and thicker until they practically monopolise the succession; these brown clays are seen stretching for a long distance north-eastwards. The more sandy phase separating the clays of "a" and "c" represents zone "b." In the southern portion of the area there is the same belt of cultivation, a similar longitudinal stream—south-easterly in this case—and rising ground beyond, but sandstone ridges, though short and inconstant, are locally as plentiful in zone "a" as in zone "b," such as those producing the hills immediately north-west of Kani Qadir; no definite line can be drawn between zones "b" and "c," the clay of the latter being redder than usual. In all three zones clay greatly predominates, and there is not so much of that regular system of parallel ridges and valleys so typical of zone "b"; the clay has thin sandy partings which indicate the dip very precisely. South-west of the Jabal Nasaz, between this range and the Zindanah ridge

zone "c" is exposed in a very broad flat anticline pitching imperceptibly south-eastwards; it contains a few thin conglomerate bands.

The Conglomeratic stage is finely exposed in the prominent scarp of the Jabal Nasaz, and in fact constitutes this range. The actual conglomerate zone, zone "d," as I have called it, reaches a greater thickness here (exaggerated in the section) than in any other locality so far visited, attaining 400-500 feet; this zone I have designated the "Nasaz zone." It consists of rapid alternations of conglomerate and subordinate sandstone bands, dipping very gently in a north-eastern direction, and producing precipitous cliffs of some magnitude on the south-west. The dip slope shows the usual intricate dissection and very rounded detail. Amongst the pebbles are numerous pebbles of Fars limestone, measuring up to one foot across. Traced south-eastwards the lower boundary swings round towards the west and the zone apparently becomes reduced to the size of the Zindanah ridge, and north-west of this, to still smaller dimensions. There appears, therefore, to be great lateral variation in this zone, as in fact in all other zones, of the Kurd series, a condition typical of a fluviatile deposit. South-west of the Zindanah ridge and forming the shallow synclinal rolling plain of the Dasht-i-Pataki, are brown clays which I have called phase or zone "e"; they contain a few stringers of gravel. None of these zones can be taken as a definite chronological division; they are more of the nature of phases which dovetail with one another, and are somewhat difficult to show on a map.

Alluvium is difficult to distinguish from the massive brown clays of zones "c" or "e," when either of the latter is nearly horizontal.

Structure.

This area is closer to the origin of the folding movement and shows greater disturbance, than any yet examined. The N.W.—S.E. anticline, beneath which the petroleum primarily collected, became a tightly compressed overfolded isocline similar to others already described. The Fars outcrop must have been very narrow, and 'ridged up' in the curious way noticed in many neighbouring anticlines, the dip rapidly steepening as the core of the fold was approached. This Fars outcrop, however, was still further narrowed by a large reversed fault which cut out part of the south-western limb. In fact an anticlinal structure cannot now be clearly demon-

strated, but is deduced by analogy with other areas. One here and there gets the impression of an arching over in the central core of limestone. This admittedly may be the result merely of the upward thrust of the beds, but, comparing it with less disturbed folds, I am more inclined to the view that the original crestal area is present and that the faulting has taken place a little to the south-west of this. Near Gil a distinct south-westerly dip flanking an arch can be seen. As already stated, in the complete north-eastern limb, the central core of limestone is succeeded by a thick bed of clay with locally some gypsum, then by a thin limestone band, and finally by several hundred feet of red clays belonging to the lowest horizons of the Kurd series. Dislocation in the south-western limb would most naturally take place along the junction of the hard central limestone core and the succeeding soft beds of Fars clay, and this, I think, is what has happened along most of its length. The section on plate 7 will illustrate this.

A traverse from north-east to south-west shows the following succession. Commencing about 4 miles east of Kani Qadir, we see the massive light brown clays of phase "c" of the Kurd beds dipping north-east at 15.° Further south-west sandstones become a little more frequent, and the dip sinks to 13° and 9.° The dip soon after begins to steepen, producing the "ridging up" referred to; one mile east of Kani Qadir it is 23°, and at the Fars upper boundary it varies from 30° to 50° with locally still greater dips. The north-eastern limb of the Fars outcrop is not unduly contorted —in fact it shows comparative regularity—but the central core of the anticline is disturbed. This core, what remains of the south-western limb, and the reversed fault, are all largely concealed by gravel and other detritus which have spilled over it from the Jabal Nasaz above. Beyond the fault south-westwards are the conglomerates of phase "d" dipping at angles scarcely more than 2° or 3° towards the north-east. The missing beds cut out by the fault, therefore, include a small thickness of the Fars, and the whole of the Lower stage of the Kurd series, *viz.*, phases "a," "b" and "c." Crossing the Jabal Nasaz the conglomerates are seen to overlie zone "c" which forms a low flat anticline between the Jabal Nasaz and the Zindanah ridge, the latter consisting of zone "d" much reduced in thickness. Still further south-west comes the flat syncline of the Dasht-i-Pataki, occupied by brown clays of phase "e," followed by a third belt of conglomerate near Balagah Rashid,

overlying beds forming the north-eastern limb of the Tuz Khurmatu-Kifri anticline. The contact of steeply dipping Fars beds with almost horizontal conglomerates along the fault is well shown in the banks of the Aq Su and a small tributary thereof; the more northerly sections show gypsum in contact with the conglomerate, while the more southerly show red clays on both sides of the gypsum, that on the south-west being contorted and in contact with conglomerate dipping at about 3° towards E.N.E. The Fars outcrop cannot be more than 20 or 30 feet across; the hade of the thrust is not clear, but has the appearance of being steep and not very far from 45.° South of Qawali the Fars outcrop, the fault and the Jabal Nasaz, all swing round towards the south, and a section in a stream shows a line of fault breccia inclined at 44,° so that the hade of the fault must be something approximating 46°; its thrust or throw must be over $1\frac{1}{2}$ miles.

The Fars outcrop, although so narrow, is surprisingly continuous. It was not seen for about three-quarters of a mile half-way between Kani Qadir and the Aq Su, but may be concealed here; small rounded boulders of limestone are plentiful, but are neither larger nor more numerous than they are in the conglomerates of the hills above, from which they may well have rolled. A line of springs occurs along or very close to the fault.

Petroleum.

Natural Indications.—Seepages of oil and sulphuretted hydrogen, accompanied by the usual sulphur deposition, are very numerous, occurring between a point $2\frac{1}{2}$ miles S.S.E. of Kani Qadir and in the vicinity of Farhad Beg. I was told that no seepages existed further north-west, but cannot vouch for the accuracy of this statement. Those observed have been indicated on the map. These seepages do not occur along the line of the great fault, but across the supposed crestal portion of the Fars outcrop, especially along the north-eastern flank of the limestone core, at its junction with the overlying clay. The following is a list of observed seepages from south-east to north-west, but there may be others:—

(*i*) $2\frac{1}{2}$ miles S.S.E. of Kani Qadir.—Sulphuretted hydrogen.
(*ii*) Immediately opposite Kani Qadir.—Sulphuretted hydrogen

(*iii*) Nuqtah Saitapah—two valleys.—Many small seepages of oil, on which pits have been dug. The oil is less tarry than usual and there is less sulphuretted hydrogen accompanying it, the aromatic odour of the oil predominating. Only 14 of these pits are at present being worked and these yield an average of 20 tins (80 gallons) a day; it is carried up to Gil (Bahram Beg) on donkeys where it is refined. The pits and seepages stretch across the Fars outcrop for a width of about 50 yards.

(*iv*) Gil (Bahram Beg).—One or two unimportant seepages. There are four small stills here, three of which are in working order; they consist simply of retort and condensing spiral.

(*v*) A short distance N.W. of Gil.—Sulphuretted hydrogen and a little bituminous earth.

(*vi*) Nuqtah Sadiq.—Two or three moderate seepages, but very little sulphuretted hydrogen.

(*vii*) Between Nuqtah Sadiq and Farhad Beg four separate oil localities are seen:

(*a*) Three small pools of oil.

(*b*) A pool of water with a little oil on the surface; just below is a sulphuretted hydrogen pool.

(*c*) Three or four pools of oil.

(*d*) Two pools of oil, one large with a considerable quantity of gas bubbling up.

(*viii*) Farhad Beg.—A seepage or two of oil. Another small refining-still is used here.

(*ix*) Half-a-mile N.W. of Farhad Beg.—A spring of water with a little oil and a considerable quantity of gas.

The refined burning oil from this area, whether due to more careful refining or to greater intrinsic purity of the crude material, is much superior to that of Tuz Khurmatu or Kirkuk.

Prospects of Boring.—The great compression of the fold and the presence, within a few yards of the supposed crest, of such a large dislocation as the reversed fault described, offer no inducement to exploitation by boring. Deep boring is, I think, out of the question; it is very improbable oil "pools" would ever be encountered sufficiently large to pay. Nor is the area much more promising for shallow boring unless some particularly inexpensive form of

plant can be devised. That the oil occurs north-east of the fault rather points to the conclusion that it has been to some extent prevented from escaping by the protective remains of some sort of anticlinal structure; the gassiness of some of the seepages may be mostly due to sulphuretted hydrogen. It seems quite probable that the plane of the fault is parallel for some way down with the axial plane of the anticline, but the latter is, in any case, too tight to hold oil in any quantity. Hand-dug wells might perhaps pay in places, and the number and liveliness of the seepages should offer some inducement to such experiments. Boring would be a pure speculation. Any tests should, of course, be located north-east of the limestone core, preferably perhaps where this is seen to form high ground.

30th March, 1919.

REPORT No. 13.—NOTES ON THE JABAL GILABAT BETWEEN CHINCHAL-AL-KABIR AND QARAH TAPPAH.

MAPS.—1 inch = 1 mile. Pl. 9, with a section.

TALISHAN ANTICLINE.

South of Kifri in the neighbourhood of Talishan a low flat anticline extends N.W.—S.E., exposing zones "c" and "d" only of the Kurd series. The conglomeratic zone "d" is exposed in the north-eastern limb of the fold, but is not very well developed: the dip here is not more than 3° or 4° and to the north-east. In the brown clays of zone "c" beneath, the dip rises to 17° in one place; the south-western limb is buried beneath alluvium. The fold probably pitches towards Talishan where the Sarchan River breaks through and rises again south-eastwards, but this was not properly determined.

JABAL GILABAT ANTICLINE.

No more Tertiary exposures are seen along the road till the bridge at Shaul Kupri is reached; here a few feet of practically horizontal, greenish and brown, banded clay are exposed in the stream and probably belong to the upper horizons of the Conglomeratic stage,

zone "e." Two miles south of this the hills of Jabal Gilabat commence to rise from the plain. The Jabal Gilabat consists of a faulted anticline extending N.W.—S.E. and pitching steadily and very gently south-eastwards towards a point three miles north of Qarah Tappah (*see* map, pl. 9). As the geological map shows, the lowest beds exposed are the sandstones of zone "b" belonging to the Kurd series. Near Kahriz Atiq the outcrop of this zone is about three-quarters of a mile wide; south-eastwards it narrows and disappears about two miles past Abu Alaik. To the north-east, the beds of this zone "b" pass up into the brown clays of zone "c" and these in turn into the conglomerates of zone "d" which form the scarp of the Jabal Gilabat proper. South-westwards, however, zone "b" is cut off by a strike fault which brings it up abruptly against zone "c." This fault, whose down-throw is on the south-west, dies out in the direction of pitch of the anticline about two-and-a-half miles from Abu Alaik. It occurs very close to the anticlinal crest. In the south-western limb of the anticline the conglomeratic zone "d" is apparently so poorly developed as to have been covered completely by alluvium up to a point two miles from Yalghuz, where it makes its appearance in the form of a narrow line of low mound-like hills. North of Qarah Tappah it is well exposed, its beds curving in broad concentric horse-shoes from one flank to the other. East of Qarah Tappah the anticline apparently rises again. In the transverse section sketched the fault is assumed to hade towards the down-throw, but no indication of the hade was seen.

Sulphur and oil.—A sulphur spring accompanied by the odour of petroleum is reported to occur a mile north-west of Abu Alaik, and is used for bathing purposes. The spring was not actually seen, but there is no doubt that it occurs on the fault (*see* section on pl. 9). In view of this fault along or very close to the crest the prospects of obtaining oil by boring are most uncertain. The only chances of success depend upon the possibility that small patches of the crest sufficiently arched to retain a little oil may remain, or that oil in some places may have been sealed off against the fault by a clay band. Boring would have to be deep. My examination was too cursory to permit of a decided opinion, but the risk of failure would certainly be great.

16th April, 1919.

REPORT No. 14.—NOTES ON THE JABAL HAMRIN BETWEEN QARAH TAPPAH AND TABLE MOUNTAIN.

MAPS.—1 inch = 1 mile. Pl. 10.

AIN LAILAH PASS.

Opposite Qarah Tappah the crest of the Hamrin Range consists, not of anticlinally folded Fars beds as it does near the Tigris, but of a scarp of the conglomeratic zone "d" of the Kurd series. The conglomerates of this zone, reinforced along the main ridge by a thick band of sandstone, dip at about 5° towards the north-east, disappearing beneath alluvium which probably covers the clays of zone "e." On the south-west side of the range the conglomerates are seen to overlie brown clays of zone "c" and these in turn sandstones of zone "b," all dipping gently and normally in a north-easterly direction.

SAKALTUTAN PASS.

Over the Sakaltutan Pass the dip in the conglomerates rises to 10°, and in the sandstones to 16°, but it waves a little in the latter (*see* map, pl. 10). Opposite Khalaf-al-Quran it was seen that the Kurd beds form the north-eastern limb of a N.W.—S.E. anticline, which is here pitching towards the north-west, the crest lying very close to the road. This crest is sharp and the anticline asymmetric, the south-westerly, dips rising to 50° and more.

TABLE MOUNTAIN.

Introduction.—Opposite Mansuriyah the anticline is well exposed and pitches south-eastwards to the small pass over the hills, east of the town. It rises again towards the river and probably reaches a crest-maximum somewhere in Table Mountain; south-east of Helio Hill it is seen pitching south-eastwards. Both limbs of the fold are represented on each bank of the river, though not much of the south-western limb has escaped concealment beneath the alluvium. North-easterly dips rise to about 18° and south-westerly to 90,° but there may be slight reversal of the latter limb beneath the alluvium.

Post-Tertiary gravel.—The most interesting feature of the Table Mountain area is the post-Tertiary gravel and silt lying unconformably upon the Tertiaries in the vicinity of the river and on

both sides of it. This gravel, which is Pleistocene or early Recent in age, is not everywhere horizontal, but has been folded into an anticline by a Recent continuation of the folding movement which had established the anticline in the Tertiary beds. The folding of the gravel has taken place naturally along the same axis as the older anticline, and we have as it were an anticline of Pleistocene or Recent Gravels capping or embracing a sharper anticline of Tertiary sandstones (*see* section). The maximum dips in the limbs of the two folds are :—

Anticline of Tertiary beds—	
S.W. flank	vertical.
N.E. „	20°.
Anticline of post-Tertiary beds—	
S.W. flank	22°.
N.E. „	3°—4°.

The south-westerly dip in the gravel is fairly distinct, and the beds can be seen arching over towards the crest. The north-easterly dip is only apparent in the general steady slope of the gravel plateau level. Since the deposition of the gravel, therefore, the south-western limb of the anticline of Tertiaries has been steepened 22° and the north-eastern limb 3° or 4°, in other words the fold has been tightened or compressed to the extent of about 25°.

Possibilities of Oil.—Natural occurrences of petroleum or sulphuretted hydrogen in the area under report, were neither noticed nor heard of. The anticline is intact and not too acutely folded, and there is an inconspicuous surface indication of sulphuretted hydrogen and petroleum in the anticline adjoining to the north-east, the Jabal Gilabat; this indication is 28 miles distant from Table Mountain, but not more than 12 miles from the axis of the Jabal Hamrin anticline. The promising oil locality of Naft Khana, north of Mandali, is not more than 20 miles north-east of Table Mountain. It is true that the presence of subterranean oil-bearing strata is usually shown at the surface by seepages, but in this case any petroliferous beds would be below a great depth of rocks, the bulk of which would consist of clays belonging to zone "a" of the Kurd series. No fault was seen up which oil might seep, but the presence of selenite at the surface along the crestal area seems to indicate that the clays have been cracked transversely or at any rate form a cap not sufficiently impervious to prevent the upward percolation of gypseous water from the Fars

below. Such radial cracking along the crest of an anticline is common and natural, the cracks being filled with calcite, gypsum, mud, etc. I have seen less promising areas than this tested in Burma. Drilling in this area would have to be deep and would be a pure gamble until more is known of the general "lie" of the oil supplies in the country and also until the Jabal Hamrin itself has been more extensively examined.

20th April, 1919.

FINAL SUMMARY REPORT.

Introduction.

In the series of reports written during the process of this survey, I have put forward freely opinions and hypotheses as they gradually developed with the work. It is now proposed to review briefly some of the points and to summarize the extent to which these opinions and suggestions have been confirmed or modified. No radical change of opinion was found necessary, but the scheme of classification naturally expanded and the theory of unconformity was tested.

Unconformity.

In Report No. 2 it was stated that, in view of the marine character of the Jabal Hamrin Fars series and the fluviatile nature of the succeeding red clays and sandstones of the Kurd series, and also in view of the correspondence in character of these Fars beds with Dr. Pilgrim's gypsum-bearing Lower Fars on the one hand, and the red clays and sandstones with his Bakhtiyari series on the other, the boundary between the two series in the Jabal Hamrin might be an unconformity, and possibly one of some magnitude locally. It was also stated that an extended examination of this boundary in other areas would be necessary to prove this one way or the other, and that there was no evidence at all in the portion of the Jabal Hamrin investigated, to prove that this unconformity was anything more than the break consequent on the change from a marine gulf to a river. It has been found possible to extend the last statement to all areas subsequently surveyed. The top bed of the Fars varied in nature from a fossiliferous limestone to a gypsum band, but to what extent this was due to lateral variation or to unconformity, it would be difficult to say; the impression gained was that this break

involved no considerable erosion between the two periods of deposition. Some geologists would perhaps not consider this large enough to be spoken of as an unconformity, and some have gone so far as to class the top gypsum or limestone band and the beds of red clay underneath it as "Passage Beds" (or Middle Fars), because they partake of the nature both of the gypsiferous series below and the red clays and sandstones above. It is largely a matter of terminology, and I see no objection to the use of either of the terms "unconformity" or "passage beds," provided it is made plain what is meant by the term. My interpretation of the sequence of events is as follows:—The gypsum-bearing series was deposited in a gulf of no great depth, which became silted up and gave place to a river, with perhaps an intermediate phase of salt lagoons. To effect this change land must have appeared and erosion to some extent at least have taken place. In this sense, therefore, there must be unconformity everywhere, while here and there erosion might be very appreciable. If it were everywhere an unconformity of any size, we must presuppose a widespread upheaval of a very gentle epeirogenic kind, but I am more inclined to the view that corrugation of the beds commenced early in the Tertiary period; if so the fairly persistent nature of the upper portion of the gypsum-bearing series and the constant way in which it is, with few exceptions, followed by the same zone of red clays (zone "a" of the Kurd series), are more in favour of the view that there was a minimum of erosion. The few exceptions in the composition of zone "a" were all obviously due entirely to local lateral variation. Before the final establishment of lagoon or fluviatile conditions, there were premature occurrences of such conditions, followed by temporary submergence beneath the gulf-waters. The last premature change of this kind occurred very generally over wide areas, producing the belt of red clays just below the topmost sedimentary gypsum band or fossiliferous limestone. This belt including the topmost marine bed I take to be the "Passage Beds" referred to. It denotes a final oscillation between marine and lagoon or fluviatile conditions; on my maps it has been included with the gypsum-bearing series below ("Fars"). I am still of opinion that localities will be found in which erosion has been greater, and the unconformity visible or demonstrable; it may very possibly be demonstrable in some of the areas mapped when more adequate maps are available.

Classification.

In view of the doubtful size of the unconformity the following question arises:—"If the gypsum-bearing beds are to be assigned to the Lower Fars, how can the succeeding red clays and sandstones be classed as Bakhtiyari?" As stated in Report No. 2, the "Gypsiferous Group" of Loftus was split up by Dr. Pilgrim into a lower series which he called Fars and an upper which he called Bakhtiyari chiefly, I take it, because the older beds are marine and the younger fluviatile, and because of a dividing unconformity. Now since the gypsum-bearing strata of the area I have been surveying certainly include marine beds, and the red clays and sandstones of the Kurd series are certainly fluviatile or lagoon or perhaps both, and since the boundary between is the only place where a widespread unconformity can possibly be allowed to exist, it seems to me very probable that taxially the Kurd beds are the equivalent of Pilgrim's "Bakhtiyaris," and, if the erosion of the gypsum beds along the boundary be small, these beds must be correlated with the higher horizons of the Fars and not with the lower. For the above reasons I have avoided the term "Lower Fars" and spoken of the beds simply as "Fars," until the question is cleared up by connected mapping between the Mosul-Baghdad-Kirkuk area and the Persian Gulf. Dr. Pilgrim concluded that the unconformity, in the Persian Gulf area, even where his upper Fars was present, was of considerable size and the result of gentle undisturbed upheaval.

Pilgrim's basal gypsum stage is described as passing up into his *Ostræa virleti* stage in which interbedded gypsum bands occur. He says, "I am not prepared to deny that the lowest beds of the *Ostræa virleti* division occurring immediately above the typical development of the gypsum beds are not contemporaneous with portions of the Fars series further north which I have classified with the basal division." There is here a distinct suggestion that the basal or gypsum stage increases northwards at the expense of the *Ostræa virleti* stage. As I have said Pilgrim was also in favour of a great unconformity between his Fars and Bakhtiyari; so that there is more than one element of uncertainty in the correlation of the Mosul-Baghdad-Kirkuk area with that of the Persian Gulf. In the circumstances I would deprecate the use of the adjectives lower, middle and upper being used for the present in connection with the Fars of Mesopotamia, and perhaps also of the term Bakhtiyari for the later series in the same region. Geology is not a mathe-

matical science and in schemes of classification—especially in the smaller sub-divisions—a compromise is always necessary between chronology and homotaxis, each of which has claims which cannot be ignored. Until we are in a better position to adjust this compromise in the case in question, it is advisable to use fresh local names. This has always been found to be the simplest solution in the long run to similar difficulties elsewhere. A multiplicity of local names, though burdensome to the memory, leads to far less confusion than the misuse and subsequent correction of established terms; it is an easy matter to drop one or more of the terms when shown to be unnecessary. For the rocks between Mosul, Kirkuk and Baghdad, all of which can be grouped under the same scheme, I am only proposing three fresh names for the present. For the gypsum-bearing group, whose base is never seen, the "Hamrin stage" of the Fars series would be appropriate. Its uppermost bed is the youngest band of white gypsum or fossiliferous limestone, and its strata, especially near the top, include short premature lagoon or river phases. This Hamrin stage includes, I think, the "Passage Beds" or "Middle Fars" of some writers as well as the Lower Fars. For zone "d" (*see* Report No. 11) of my Kurd series, I propose the term "Nasaz zone" after the range in which it is so strongly developed. The expression "Red Clay and Sandstone series" originally used in my reports, was a cumbrous title, for which the term "Kurd series" is considered an apt substitute; further investigation will show to what extent it is synonymous with the Bakhtiyari series.

The various stages and zones recognizable in this Kurd series have been carefully described in Report No. 11. The two stages, upper and lower are always readily distinguishable in a sufficiently complete succession, but occasionally, through local lateral variation, it is not always easy to differentiate all the zones, especially "a" and "b." My zones "a," "b" and "c"—*i.e.*, the Lower stage of the series—seem to correspond fairly closely with the Upper Fars of the observers referred to, while zone "d," with the doubtful zone "e," corresponds to their Bakhtiyari, up into which they speak of their Upper Fars as passing. I have not attempted to map all the zones in my earlier maps chiefly on account of the lack of sufficient topographic detail thereon, but they can be readily identified in the Jabal Hamrin, Jabal Makhul and other localities.

Conglomerates.

It requires experience to be able to distinguish the conglomerate of the Conglomerate stage (Nasaz zone) from Pleistocene or Recent conglomerates and gravels, especially in the neighbourhood of large rivers. As the pebbles of the younger are precisely similar to, and probably nearly all derived from, the older conglomerate, there is no distinction in character between them, and position and dip are the most important criteria. Some of the thinner layers in the Nasaz zone are scarcely more than stringers of loose gravel, while the younger Pleistocene deposit, on the other hand, may be a very hard tough conglomerate, such as that on the cliffs above Qal'at-al-Bint. In widely isolated exposures it is sometimes impossible to determine the age of a more or less horizontal conglomerate.

Formation of Hydrogen Sulphide.

In Report No. 2 it was suggested that the hydrogen sulphide associated with the tarry oil and bitumen seepages, might be the outcome of some chemical action between crude petroleum and sulphates, more especially between petroleum and gypsum, the sulphuric acid radical of the latter being thereby reduced to hydrogen sulphide. Subsequent experience abundantly supports this view which is not a new one, but has been brought forward by others to explain similar phenomena in other countries. Beyerinck and also Saltet have shown that oxygenated sulphur compounds are reduced by anærobic bacteria to hydrogen sulphide in the presence of dead organic matter. It is very unlikely, however, that such organisms can exist at any appreciable depth below the surface, but experiments by Kharitschoff show that similar reduction of sulphates in solution—gypsum and to a still greater extent magnesium sulphate—are brought about slowly, especially under high pressure and temperature, by hydrocarbons. Höfer gives equations representing this change :—

$$CaSO_4 + CH_4 = CaO + H_2S + CO_2 + H_2O.$$

or :—

$$CaSO_4 + CH_4 = CaS + CO_2 + 2\ H_2O = CaCO_3 + H_2S + H_2O.$$

As Mr. Sherburne Rogers remarks, these should be taken merely as type equations, true for the higher hydrocarbons, since *methane*

itself is one of the most stable of hydrocarbons and would probably be the last to undergo any change. It was for a long time thought that bitumen and asphalt were oxidised products of various hydrocarbons and contained oxygen,[1] but Mr. Clifford Richardson has shown that oxygen is not a constituent of asphalt to any appreciable extent, while sulphur is.[2] He found that asphalt consists chiefly of unsaturated hydrocarbons and is characterised by the presence of mercaptans and other sulphur derivatives. He concluded that asphalt "does not originate as such, but is a secondary product, resulting from the transformation of lighter forms of bitumen, malthas, or even thinner oils, into harder bitumen by condensation and polymerization, a reaction in which sulphur seems to take an important part ..... No high temperatures seem necessary for the change once initiated, as it is seen going on to-day in the Trinidad Pitch Lake and in Venezuela. Gas is commonly evolved and is largely hydrogen sulphide, the natural result of the condensation of hydrocarbons by sulphur. Carbonic acid accompanies it which would seem to point to a reaction between hydrocarbons and inorganic sulphates and the latter as the source of the sulphur in the bitumen of asphalts."[3] He goes on to say, however, that "this is only theory based on the presence of sulphates in the water emulsified with Trinidad pitch, while there is quite as much hydrogen sulphide given off by the Bermudez asphalt which contains no water or sulphates as it originates." In the Mesopotamian seepages the accompaniment of sulphate-bearing water is very common but not invariable or at any rate not continuous. It seems to me highly probable that some of the less stable hydrocarbon members break down by the action of calcium sulphate in some such way as Höfer's formulæ depict, producing hydrogen sulphide and carbonate of lime. Sometimes all the carbon dioxide is not taken up by the lime and portions of it escape in seepage and oil-well waters. Mr. Sherburne Rogers found this gas very frequently in the waters of the Coalinga oilfield. The hydrogen sulphide also partially escapes as such and is partially taken up by the hydrocarbons to form sulphur derivatives. Polymerization accompanies all these processes and the total result appears to be exothermic, since a slightly raised temperature usually characterises sulphur-bearing

[1] Dana's "Mineralogy."
[2] *Journ. Soc. Chem. Industry*, Vol. XVII, p. 30 (1898).
[3] *loc. cit*, p. 31.

seepage and oil-well waters; the baths of Hammam Ali are an example of this. Rogers formed the opinion that hydrogen sulphide in the Coalinga and other oil-fields of California was probably produced by the reduction of sulphate by hydrocarbons.[1] That this is the case in Mesopotamia is borne out by the fact that petroleum indications, occurring as they do in a highly gypsiferous series, are, so far as my experience goes, invariably accompanied by hydrogen sulphide. It cannot be maintained that the converse is invariably true, but my experience has been that on searching long enough and deep enough immediately around the vent of any hydrogen sulphide emanation, bituminous earth will in nearly all cases be found. The question is of considerable economic importance, since it renders a hydrogen sulphide emanation almost equal in importance to an oil seepage, as an indication of the presence of oil below the surface. Numbers of these "sulphur springs" have been marked on the maps and are reported constantly by native inhabitants, and nearly all those I have examined, have proved to be bituminous to a greater or less extent.

Date of Movement.

Flexuring of the Tertiary rocks into anticlines and synclines took place of course after the deposition of these rocks, *i.e.*, in post-Tertiary times, but indications are not wanting that this lateral disturbance had commenced as early at least as the beginning of the Kurd or Bakhtiyari period, and probably in the Fars period; whether it preceded the latter will be known perhaps when the Nummulitic series has been surveyed. This movement probably continued unevenly during the deposition of the whole of the Kurd red clays and sandstones and undoubtedly survived the last recorded zones "d" and "e." The indications of an early commencement of the movement may be summarised as follows:—

(*i*) The rapid steepening of the dip in the more compressed folds in passing from the lowest zone of the Kurd series down into the Fars, may be explained—among other ways—on this assumption. This rapid steepening or erection of the anticlinal core was noticed in all the compressed folds examined. A similar steepening occurs in Burma in the neighbourhood of the junction of the

[1] *United States Geol. Sur.* Bull. 653 (1917), p. 114.

petroliferous marine series with the overlying fluviatile deposits, and is attributable probably to the same cause.

(*ii*) At the commencement of a movement the tension produced tends to be taken up equally by the anticlines and synclines at regular intervals and more or less equal amplitudes. The anticlines, however, first come under denuding influences and, as a result, yield more readily to the lateral pressure than the synclines, in which deposition is still proceeding. In other words there must always be a tendency for anticlines to be a little sharper and tighter than the intervening synclines. If the movement commenced during the initial stages of deposition of the sediments now forming these anticlines and synclines, this characteristic would become much more strongly marked, and it can be readily understood how the continued movement would be expended in overfolding and thrusting along these anticlinal lines of weakness rather than in tightening the synclines. The long, very flat, gentle, undisturbed synclines separating the tightly compressed, overfolded and fold-faulted anticlines, in Mesopotamia are more easily comprehensible on this hypothesis. An apparent exception to this rule is to be observed in the low, flat, very broad anticline, south-west of the Jabal Nasaz, occurring in the region of tight anticlinal folds. This, to my mind however, is an exception which merely illustrates the rule, for the anticline has every appearance of having been recently initiated in the midst of an unusually broad and flat syncline; no doubt as movement proceeds and denudation keeps pace with it, the flexuring effect will become more and more localised along the crestal area of the anticline and the latter more compressed than the synclines on either flank. Throughout the area covered by my survey, on the other hand, no tight, compressed synclines were seen at all, the subsidiary wrinkling in anticlinal flanks being on too minute a scale to affect the question.

There are indications in the Table Mountain area that the folding movement not only preceded the end of the Tertiary period but also continued into the Recent period. (*See* Report No. 14, p. 65.)

ECONOMIC QUESTIONS.

Petroleum.

In the area under consideration, and probably throughout Mesopotamia, the mineral of unique and outstanding importance is petroleum. It is perhaps unnecessary to point out that its occurrence, on account of the extreme mobility of the mineral, is a subject of considerable complexity and of many limitations. Bearing in mind, therefore, the uncertainty of prognostication on such a subject, my opinion, based on evidence collected over a fairly extended tour, is that the country will probably take a not unimportant place among the world's sources of petroleum. It should rival the Persian fields, and collectively outclass those of Burma. Below is a list of oil localities surveyed, which I have attempted to classify in the order of their promise. That is to say, leaving out the question of the size of the field,[1] these localities are arranged more or less in order according to the degree of certainty or probability that oil is obtainable in remunerative quantity.

A.—Areas of First Class importance.

1. *Qaiyarah.*—Probably a large field extending with interruptions to Qishlah and perhaps beyond. (Report 4.)
2. *Quwair.*—A small but well-defined field. (Rep. 8.)

B.—Areas less certain but of decided promise.

1. *Jabal Hamrin and Makhul near the Tigris.*—If petroliferous, probably a large field. (Rep. 2.)

C.—Areas of uncertain prospects but sufficiently promising to warrant a test boring.

1. *Jabal Mishrak.*—(Rep. 5.)
2. *Hawi Arslan.*—A very small area. (Rep. 6.)
3. *Kirkuk.*—Scarcely promising enough, to warrant deep-boring for which I should class it in E. between 3 and 4. For shallow bores a small unimportant field is possible. (Rep. 9.)

[1] This proviso explains anomalies such as the priority of a poor area like Kirkuk over areas like Kharrar or Hammam Ali, either of which *may* prove to be of much greater importance.

D.—Areas whose prospects depend more or less on the success or failure of certain neighbouring areas.

1. *Jabal Khanuqah.*—Depending on results in the *Jabal Makhul* (Rep. 3.)
2. *Kharrar.*—Depending on results in the *Jabal Mishrak.* (Rep. 5.)
3. *Hills W. of Hammam Ali and ground N.W. of Shura.*—Doubtful and depending on any success in the Hammam Ali area—should be mapped on a large scale if boring in the latter should prove successful. (Rep. 5.)
4. *Humairah.*—Depending on Hawi Arslan. A small area (Rep. 6.)

E.—Areas of speculative location.

1. *Hammam Ali, including, to the N.N.W. the Huslaun plain and hills between Lazaka and Abu Sif, to the S.S.E. the Yuhainah plain, and E'wards the islands in the river.*—Purely speculative in so far as the location of the boring is concerned, but almost fit to be classed at the base of C or with No. 2 in D, if the location of the test were not so difficult. (Reps. 5 and 6.)
2. *Nimrud.*—Speculative as the structure is hidden beneath alluvium. Otherwise fit for the base of C, since the situation is favourable, the presence of a gentle anticlinal fold very probable, and the seepages "lively" and fairly copious. (Rep. 6.)

F.—Purely speculative areas.

1. *Tuz Khurmatu.*—A speculation even for shallow boring, and unimportant as regards quantity. (Rep. 11.)
2. *Kani Qadir.*—A pure gamble even for shallow bores. Large quantities of oil very improbable. (Rep. 12.)
3. *Table Mountain.*—Structure favourable, but no surface indication of oil noticed. (Rep. 14.)
4. *Judaidah.*—Area probably restricted and prospects doubtful. (Rep. 6.)
5. *Jabal Gilabat.*—A gamble and an expensive one since boring would have to be deep. (Rep. 13.)

Pitch and Bitumen.

The only locality seen in which pitch and bitumen occur in any appreciable quantity is Qaiyarah, where however the supply is by no means unlimited (Rep. No. 4, pp. 21-22). This and the Hit deposits do not make a good fuel, and moreover would probably be of considerably greater value for other purposes such as :—

(*i*) Caulking, and ship-building on the Arab plan.
(*ii*) Use on roads.
(*iii*) Low-grade varnishes for iron-work, and japanning.
(*iv*) Use on the iron-plates of ship-bottoms to prevent electrolytic action.
(*v*) Coating masonry.
(*vi*) Acid-proof linings for chemical tanks.
(*vii*) Roofing.
(*viii*) Insulating electric wires.
(*ix*) Substitute for rubber in garden hose.
(*x*) Binding for coal briquettes.

Sulphur.

Attention has been drawn in these reports to the supplies of sulphuretted hydrogen which are available in this country. Most of the occurrences are, of course, of no economic importance, but two have been named as probably remunerative, *viz.*, (i) The junction of the Greater Zab with the Tigris (Report No. 7) and (ii) North of Kirkuk (Report No. 9, p. 44). No. (i) is by far the more important of the two. In addition to these supplies, this gas will, in all probability, be given off in large quantities from the oil of shallow oil horizons, when these are tapped by boring. Any simple device to collect it from the well-heads and oxidise it to free sulphur, either by incomplete combustion—$H_2S+O = H_2O+S$—or by mixture with sulphur dioxide—$2H_2S+SO_2 = 2H_2O+3S$—would prevent the waste of a valuable product. The device would have to be more or less portable and must not threaten the oil-fields with fire or explosion.

Gypsum.

The quantity of gypsum in the country is, from a practical point of view, unlimited. It is used by the Arabs for making

jus, an inferior plaster for their houses, and as an ornamental building-stone. The only place during my tour, in which I have seen it used extensively for the latter purpose, is Mosul. I wonder it is not more employed in this way by villagers. It is better than mud, even as a flooring—for which it is somewhat soft—and would be much cleaner. It makes serviceable and not unattractive window-plinths. It is easily quarried and dressed, though of small permanence and therefore unsuitable for buildings of any importance and size.

Gypsum is, of course, the source of Plaster of Paris, for which unfortunately there is a very limited market. No other extensive use for it has been found, so far as I know. Sulphuric acid can be manufactured from it by the simple application of heat, but the temperature requisite is comparatively high. This method of sulphuric acid manufacture was, I believe, actually tried on a commercial scale in Germany, but was apparently unable to compete with supplies derived from iron pyrites. Whether the association of unlimited gypsum with large quantities of liquid fuel, aided by the high cost of transport of imported sulphuric acid would enable the Gypsum-process to compete more successfully—locally at any rate—with the Sulphide-method, is a matter perhaps worth the attention of industrial firms. Personally, I think there is more chance of success in utilising the sulphuretted hydrogen emanations for this purpose; other things being equal it has at least the advantage over the pyrites method in that no roasting is required to obtain the sulphur dioxide.

Building-Stone.

The sandstones of the Kurd series are, with rare exceptions too soft and incoherent for building purposes. The exceptions are occasional thin bands, not more than 1 or 1½ feet thick, of a fairly tough well-bedded iron-stained mudstone or fine sandstone sometimes seen in the lowest zone. The cellular Fars limestones are not very desirable material, but the more solid limestones, especially the "Pelecypod bed," would do sufficiently well for building. The latter is not very thick—a foot or two at the most—but its upper and lower boundaries are parallel plane surfaces, which would simplify quarrying and dressing.

Road-metal.

Attention has been drawn in Reports Nos. 1 and 5 (pp. 3 and 30) to the suitability of the larger pebbles of the conglomerates and gravels, when broken up, for road-metal.

Water.

There are good prospects of obtaining potable artesian water in any of the broad flat synclines in which the Conglomerate stage is present. The conglomerates usually contain sufficient sandstone to store water, and the underlying thick massive clay of zone "c" would act as a basin. The same may be said also for any synclines in which zone "b" is within reach of an artesian boring, as it also is usually underlain by massive clay, and is an eminently porous zone. Unfortunately it is not in these synclines that artesian water is usually required, since the conglomerates are generally the source of streams which, in the cold months at any rate, attain some size. It is difficult to treat the water question from a general point of view, and it will, I think, be best to deal with any proposed area individually and on its own merit.

26th April, 1919.

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Part 4 (out of print).—Pseudo-Fucoids from Pab sandstones at Fort Munro, and from Vindhyan series. Jadelite in Kachin Hills, Upper Burma. Wetchok-Yedwet Pegu outcrop, Magwe district, Upper Burma. Group of Manganates, comprising Hollandite, Psilomelane and Coronadite. Occurrence of Wolfram in Nagpur district, Central Provinces. Miscellaneous Notes. Index to Volume XXXVI.

Vol. XXXVII, 1908-09.

Part 1 (out of print).—General report for 1907. Mineral Production of India during 1907. Occurrence of striated boulders in Blaini formation of Simla. Miscellaneous Notes.

Part 2 (out of print).—Tertiary and Post-Tertiary Freshwater Deposits of Baluchistan and Sind. Geology and Mineral Resources of Rajpipla State. Suitability of sands in Rajmahal Hills for glass manufacture. Three new Manganese-bearing minerals :—Vredenburgite, Sitaparite and Juddite. Laterites from Central Provinces. Miscellaneous Notes.

Part 3 (out of print).—Southern part of Gwegyo Hills, including Payagyigon-Ngashandaung Oil-field. Silver-lead mines of Bawdwin, Northern Shan States. Mud volcanoes of Arakan Coast, Burma.

Part 4.—Gypsum Deposits in Hamirpur district, United Provinces. Gondwanas and related marine sedimentary system of Kashmir. Miscellaneous Notes. Index to Volume XXXVII.

Vol. XXXVIII, 1909-10.

Part 1.—General report for 1908. Mineral Production of India during 1908.

Part 2.—Ostrea latimarginata in " Yenangyaung stage " of Burma. China-clay and Fireclay deposits in Rajmahal Hills. Coal at Gilhurria in Rajmahal hills. Pegu Inlier at Ondwe, Magwe district, Upper Burma. Salt Deposits of Rajputana. Miscellaneous Notes.

Part 3.—Geology of Sarawan, Jhalawan, Mekran and the State of Las Bela. Hippurite-bearing Limestone in Seistan and Geology of adjoining region. Fusulinidæ from Afghanistan. Miscellaneous Notes.

Part 4.—Geology and Prospects of Oil in Western Prome and Kama, Lower Burma (including Namayan, Padaung, Taungbogyi and Ziaing). Recorrelation of Pegu system in Burma with notes on Horizon of Oil-bearing Strata (including Geology of Padaukpin, Banbyin and Aukmanein). Fossil Fish Teeth from Pegu system, Burma. Northern part of Yenangyat Oilfield. Iron Ores of Chanda, Central Provinces. Geology of Aden Hinterland. Petrological Notes on rocks near Aden. Upper Jurassic Fossils near Aden. Miscellaneous Notes. Index to Volume XXXVIII.

Vol. XXXIX, 1910.

Quinquennial Review of Mineral Production of India during 1904 to 1908.

Vol. XL, 1910.

Part 1.—Pre-Carboniferous Life-Provinces. Lakes of Salt Range in the Punjab. Preliminary survey of certain Glaciers in Himalaya. D.—Notes on certain glaciers in Sikkim. New Mammalian Genera and Species from Tertiaries of India.

Part 2 (out of print).—General Report for 1909. Mineral Production of India during 1909.

Part 3.—Revised Classification of Tertiary Freshwater Deposits of India. Revision of Silurian-Trias Sequence in Kashmir. Fenestella-bearing beds in Kashmir.

Part 4.—Alum Shale and Alum Manufacture, Kalabagh, Mianwali district, Punjab. Coalfields in North-Eastern Assam. Sedimentary Deposition of Oil. Miscellaneous Notes. Index to Volume XL.

Vol. XLI, 1911-12.

Part 1.—Age and continuation in Depth of Manganese-ores of Nagpur-Balaghat Area, Central Provinces. Manganese-ore deposits of Gangpur State, Bengal, and Distribution of Gondite Series in India. Baluchistan Earthquake of 21st October, 1909. Identity of Ostrea Promensis, Noetling, from Pegu System of Burma and Ostrea Digitalina, Eichwald, from Miocene of Europe. Mr. T. R. Blyth. Miscellaneous Notes.

Part 2.—General report for 1910. Devonian Fossils from Chitral, Persia, Afghanistan and Himalayas. Sections in Pir Panjal Range and Sind Valley, Kashmir.

Part 3.—Mineral Production of India during 1910. Samarskite and other minerals in Nellore District, Madras Presidency. Coal in Namchik Valley, Upper Assam. Miscellaneous Notes.

Part 4.—Pegu-Eocene Succession in Minbu District near Ngape. Geology of Henzada District Burma. Geology of Lonar Lake, with note on Lunar Soda Deposit. International Geological Congress of Stockholm. Miscellaneous Notes. Index to Volume XLI.

Vol. XLII, 1912.

Part 1.—Survival of Miocene Oyster in Recent Seas. Silurian Fossils from Kashmir. Blödite from Salt Range. Gold-bearing Deposits of Mong Long, Hsipaw State, Northern Shan States, Burma. Steatite Deposits, Idar State. Miscellaneous Notes.

Part 2.—General Report for 1911. Dicotyledonous Leaves from Coal Measures of Assam. Poting Glacier, Kumaon, Himalaya, June 1911. Miscellaneous Notes.

Part 3.—Mineral Production of India during 1911. Kodurite Series.

Part 4.—Geological Reconnaissance through Dehong Valley, being Geological Results of Abor Expedition, 1911-12. Traverse Across the Naga Hills of Assam. Indian Aërolites. Miscellaneous Notes.

Vol. XLIII, 1913.

Part 1.—General Report for 1912. Garnet as a Geological Barometer. Wolframite in Tavoy District, Lower Burma. Miscellaneous Notes.

Part 2 (out of print).—Mineral Production of India during 1912. Relationship of the Himalaya to the Indo-Gangetic Plain and the Indian Peninsula. Hambergite from Kashmir.

Part 3.—Contributions to the geology of the Province of Yünnan in Western China : I. Bhamo-Têng-Yüeh Area. II. Petrology of Volcanic Rocks of Têng-Yüeh District. The Kirana Hills. Banswal Aerolite.

Part 4.—Gold-bearing Alluvium of Chindwin River and Tributaries. Correlation of Siwaliks with Mammal Horizons of Europe. Contributions to the Geology of the Province of Yünnan in Western China : III. Stratigraphy of Ordovician and Silurian Beds of Western Yünnan, with Provisional Palæontological Determinations. Notes on "Camarocrinus Asiaticus" from Burma.

Vol. XLIV, 1914.

Part 1.—General Report for 1913. Carbonaceous Aërolite from Rajputana. Nummulites as Zone Fossils, with description of some Burmese species.

Part 2.—Contributions to the Geology of the Province of Yünnan in Western China : IV. Country around Yünnan Fu. Dyke of White Trap from Pench Valley Coalfield, Chhindwara District, Central Provinces. Mineral concessions during 1913.

Part 3.—Coal-seams near Yaw River, Pakokku District, Upper Burma. The Monazite Sands of Travancore. Lower Cretaceous Fauna from Gieumal Sandstone and Chikkim series. Indarctos salmontanus Pilgrim. Future Beheading of Son and Rer Rivers by Hasdo.

Part 4.—Salt Deposits of Cis-Indus Salt Range. Teeth referable to Lower Siwalik Creodont genus Dissopsalis, Pilgrim. Glaciers of Dhauli and Lissar Valleys, Kumaon Himalaya, September 1912. Miscellaneous Notes.

Vol. XLV, 1915.

Part 1.—New Siwalik Primates. Brachiopoda of Namyau Beds of Burma. Miscellaneous Note.

Part 2.—General Report for 1914. Note on Sivaelurus and Paramachaerodus.

Part 3.—Mineral Production of India during 1914. Three New Indian Meteorites : Kuttippuram, Shupiyan and Kamsagar. Dentition of Tragulid Genus Dorcabune. Hematite Crystals of Corundiform Habit from Kajlidongri, Central India.

Part 4.—Geology of country near Ngahlaingdwin. Geology of Chitral, Gilgit and Pamirs.

Vol. XLVI, 1915.

Quinquennial Review of Mineral Production of India for 1909 to 1913.

Vol. XLVII, 1916.

Part 1.—General Report for 1915. Eocene Mammals from Burma. Miscellaneous Notes.

Part 2.—The Deccan Trap Flows of Linga, Chhindwara District, Central Provinces. Iron Ore Deposits of Twinngé, Northern Shan States.

Part 3.—Obituary : R. C. Burton. The Mineral Production of India during 1915. Flemingostrea, as eastern group of Upper Cretaceous and Eocene Ostreidæ, with descriptions of two new species.

Part 4.—Contributions to the Geology of the Province of Yünnan in Western China : V. Geology of parts of the Salween and Mekong Valleys. A fossil wood from Burma. The Visuni and Ekh Khera Aerolites.

VOL. XLVIII, 1917.

Part 1.—General Report for 1916. A revised classification of the Gondwana System.
Part 2.—Mineral Production of India during 1916. Mammal collections from Basal Beds of Siwaliks.
Part 3.—Crystallography and Nomenclature of Hollandite. Geology and Ore Deposits of Bawdwin Mines. Miscellaneous Notes.
Part 4.—Biana-Lalsot Hills in Eastern Rajputana. Origin of the Laterite of Seoni, Central Provinces.

VOL. XLIX, 1918-19.

Part 1.—General Report for 1917. Cassiterite Deposits of Tavoy. Les Echinides des "Bagh Beds."
Part 2.—Mineral Production of India during 1917. Support of Mountains of Central Asia.
Part 3.—Structure and Stratigraphy in North-West Punjab. Aquamarine Mines of Daso, Baltistan. Srimangal Earthquake of July 8th, 1918.
Part 4.—Possible Occurrence of Petroleum in Jammu Province : Preliminary Note on the Nar-Budhan Dome, of Kotli Tehsil in the Punch Valley. Submerged Forests at Bombay. Infra-Trappeans and Silicified Lava from Hyderabad, S. India.

VOL. L, 1919.

Part 1.—General Report for 1918. Potash Salts of Punjab Salt Range and Kohat. Origin and History of Rock-salt Deposits of Punjab and Kohat.
Part 2.—Tungsten and Tin in Burma. Inclination of Thrust-plane between Siwalik and Murree zone near Kotli, Jammu. Two New Fossil Localities in Garo Hills. Sanni Sulphur Mine. Miscellaneous Notes.
Part 3.—Mineral Production of India during 1918. Gastropoda Fauna of Old Lake-beds in Upper Burma. Galena Deposits of North Eastern Putao.
Part 4.—Pitchblende, Monazite and other minerals from Pichhli, Gaya district, Bihar and Orissa. Natural Gas in Bituminous Salt from Kohat. Mineral Resources of Central Provinces. Miscellaneous Notes.

VOL. LI, 1920-21.

Part 1.—General Report for 1919. Pseudo-crystals of Graphite from Travancore. Mineral related to Xenotime from Manbhum District, Bihar and Orissa Province. Coal Seams of Foot-Hills of the Arakan Yoma, between Letpan Yaw in Pakokku and Ngapè in Minbu, Upper Burma. Observations on "Physa Prinsepii," Sowerby and on a Clionid Sponge that burrowed in its shell.
Part 2.—Classification of fossil Cypræidæ. Sulphur near the Confluence of the Greater Zab with the Tigris, Mesopotamia. Miscellaneous Notes.
Part 3.—Mineral Production of India during 1919. Results of a Revision of Dr. Noetling's Second Monograph on the Tertiary Fauna of Burma. Note on the Marine Fossils collected by Mr. Pinfold in the Garo Hills.
Part 4.—Illustrated comparative Diagnoses of Fossil Terebridæ from Burma. Indian Fossil Viviparæ. On a new fossil Unionid from the Intertrappean beds of Peninsular India. Unionidæ from the Miocene of Burma.

VOL. LII, 1921.

Quinquennial Review of Mineral Production of India for 1914 to 1918.

VOL. LIII, 1921.

Part 1.—General Report for 1920. Antimony deposit of Thabyu, Amherst district. Antimony deposits of Southern Shan States. Geology and Mineral Resources of Eastern Persia. Miscellaneous Notes.

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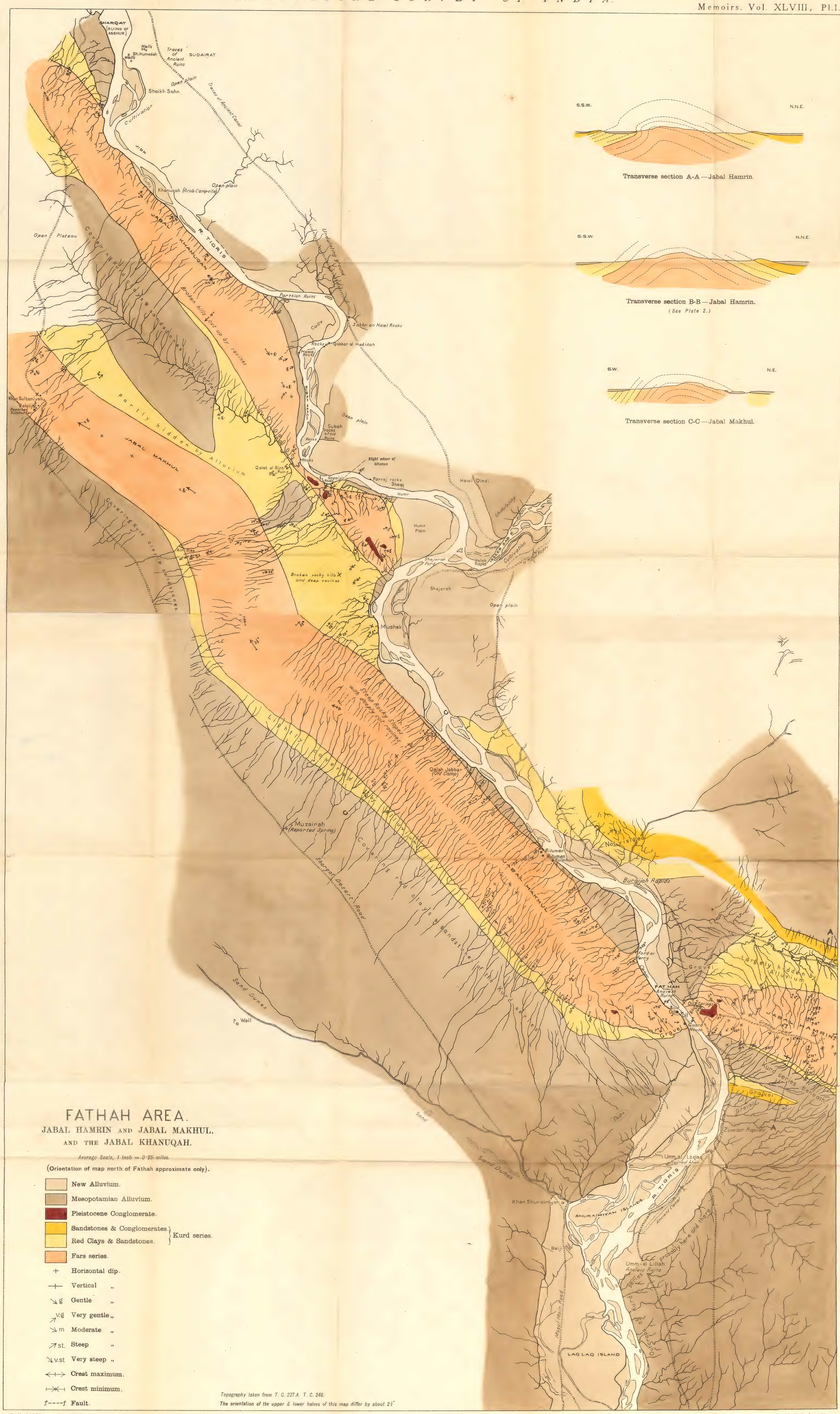


S.S.W. N.N.E.

Transverse section A-A — Jabal Hamrin.

S.S.W. N.N.E.

Transverse section B-B — Jabal Hamrin.

(See Plate 2.)

S.W. N.E.

Transverse section C-C — Jabal Makhul.

FATHAH AREA.

JABAL HAMRIN AND JABAL MAKHUL, AND THE JABAL KHANUQAH.

Average Scale, 1 Inch = 0·95 miles.

(Orientation of map north of Fathah approximate only).

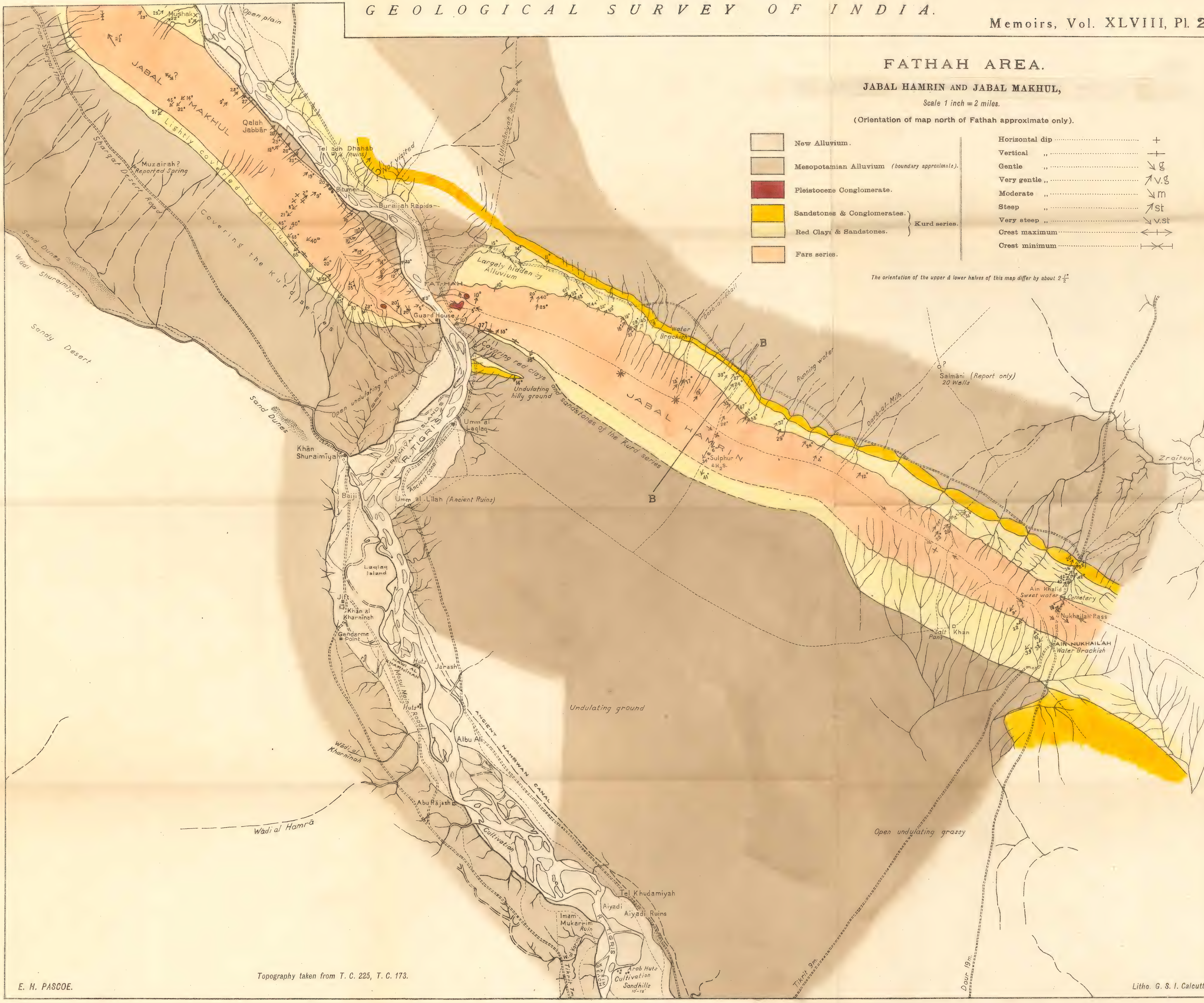
- New Alluvium.
- Mesopotamian Alluvium.
- Pleistocene Conglomerate.
- Kurd series: Sandstones & Conglomerates.
- Kurd series: Red Clays & Sandstones.
- Fars series.
- \+ Horizontal dip.
- —+— Vertical „
- ↘ g Gentle „
- ↗ v.g Very gentle „
- ↘ m Moderate „
- ↗ st. Steep „
- ↘ v.st Very steep „
- ←+→ Crest maximum.
- ⊢✳⊣ Crest minimum.
- f----f Fault.

Topography taken from T. C. 227 A. T. C. 248.

The orientation of the upper & lower halves of this map differ by about 2½°

E. H. PASCOE. Dec. 1918.

Litho. G. S. I. Calcutta.


FATHAH AREA.
JABAL HAMRIN AND JABAL MAKHUL,
Scale 1 inch = 2 miles.
(Orientation of map north of Fathah approximate only).
New Alluvium.
Mesopotamian Alluvium (boundary approximate).
Pleistocene Conglomerate.
Sandstones & Conglomerates.
Red Clays & Sandstones.
Kurd series.
Fars series.
Horizontal dip
Vertical ,,
Gentle ,,
Very gentle ,,
Moderate ,,
Steep ,,
Very steep ,,
Crest maximum
Crest minimum
g
v.g
m
st
v.st
The orientation of the upper & lower halves of this map differ by about 2½°
JABAL MAKHUL
JABAL HAMRIN
Mushaky
Open plain
Qalah Jabbār
Tel adh Dhahab (ruins)
Not visited
Muzairah? Reported Spring
Lightly covered by Alluvium
Covering the Kurd series
Shargat Desert Road
Bitumen
Buraijah Rapids
Largely hidden by Alluvium
FATHAH
Guard House
Covering red clays and sandstones of the Kurd series
Undulating hilly ground
Sand Dunes
Wadi Shuraimiyah
Sandy Desert
Open undulating ground
Khān Shuraimīyah
Umm al Laqlaq
R. TIGRIS
Ancient Canal
Umm al-Lilah (Ancient Ruins)
Baiji
Laqlaq Island
Jift
Khān al Kharninah
Gendarme Point
Huts
Jarash
Mosul Main Road
Wadi al Kharninah
Albu Ali
ANCIENT NAHRWAN CANAL
Abu Rajash
Wadi al Hamrā
Cultivation
Undulating ground
Open undulating grassy
Brackish water
Running water
Darb-al-Khail
Darb-al-Milh
Salmāni (Report only) 20 Wells
Sulphur & H_2S
Zraitun R.
Ain Khalid Sweet water
Cemetery
Nukhailah Pass
Salt Pans
Khan
AIN NUKHAILAH Water Brackish
Tel Khudamiyah
Aiyadi
Aiyadi Ruins
Imam Mukarrim Ruin
Arab Huts
Cultivation
Sandhills
Tikrit 9m.
Daur 19m.
to Ulmaliyah 9m.
B
E. H. PASCOE.
Topography taken from T. C. 225, T. C. 173.
Litho. G. S. I. Calcutta.

COUNTRY BETWEEN MOSUL AND SHARQAT INCLUDING THE QAIYARAH AREA.

Scale, 1 inch = 2 miles.

Transverse section A-A — Jabal Qaiyarah.
Scale, 1 inch = 1 mile.

Transverse section B-B — Jabal Qaiyarah.
Scale, 1 inch = 1 mile.

- New Alluvium.
- Mesopotamian Alluvium.
- Kurd series: Upper (Conglomerate) stage (zone *d*); Lower stage (zones *a, b & c*)
- Fars series.
- v.g Very gentle dip.
- g Gentle „
- m Moderate „
- st. Steep „
- Variable „
- Horizontal beds.
- Waving, almost horizontal beds.
- Crest maximum.

E. H. PASCOE.

Topography taken from T. C. 171, T. C. 250 & T. C. 254.

Reg. No. 4144 E. 20

Del. G. S. I. Calcutta.

Heliozincographed at the Survey of India Offices, Calcutta

THE QUWAIR DOME

AND

COUNTRY BETWEEN QUWAIR AND ALTUN KUPRI.

Scale $\frac{1}{2}$ inch = 1 mile.

- New Alluvium.
- Mesopotamian Alluvium.
- Kurd series.
  - Upper (Conglomerate) stage (zone *d* and perhaps *e*.)
  - Lower stage (zones *a*, *b* & *c*.)
- Fars series.

Dips.

- Very gentle dip. ---> v. g
- Gentle ,, ---> g
- Moderate ,, ---> m
- Steep ,, ---> st.
- Very steep ,, ---> v. st
- Vertical beds. ---+---

Topography taken from T. C. 172, T. C. 250 & T. C. 254.

E. H. PASCOE. Jan. 1919.

Reg. No. 4144 E 20

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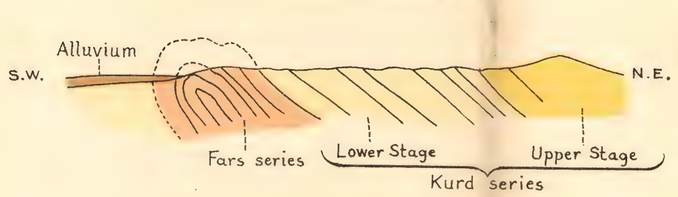
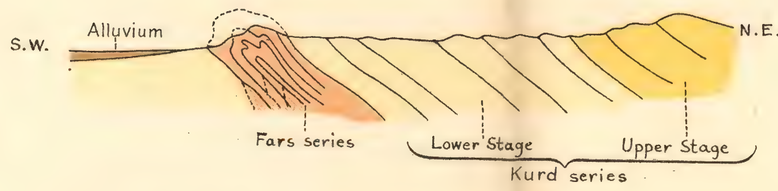
TRANSVERSE SECTIONS ACROSS THE KIRKUK ANTICLINE.

Scale, 1 inch = 1 mile.



Section A-A.



Section B-B.

THE KIRKUK AREA.

Scale, 1 inch = 1 mile.

- New Alluvium.
- Mesopotamian Alluvium.
- Upper Conglomerate stage. } Kurd series.
- Lower stage. }
- Fars series.
- Dips.
- Gentle dips. g
- Steep ,, st.
- Moderate ,, m
- Waving ,,
- Vertical beds.
- Horizontal ,,
- Contorted ,,

Kālur · Altun kupri, 16 m. · Mayar R. · Dārāmāh · Sakizli · Gravelly Ravines · Covering Conglomerate stage · Gravelly Ravines · SHAMASHĪN DAGH · Many Ravines · Qushlah · Sekani · BĀBĀ GURGUR · Cairn · H_2S · Oil spring · Tar · Bituminous Earth · Gumbarli · Section A · Hasan Ali (deserted) · Hissar · Fr. Dubisah · Āgdāsh Su · Fr. Malhah · Kulmer Tph · Ballawah · Unsurveyed · Shorau · Qāzah Chai · Yarvali ? Ford · Gravel · Rocky · Foreshore · KIRKUK · Taba Effendi Garden · Sultān Saki Tph · Sultān Saki · Bāziyan · Cultivation · JABAL BUĀR · Unsurveyed · CHARDAGHĪL DĀGH · Tel-Daiqub · Tel Jalāu? · Talau (west) · Hekarez · Fr. Tazah Khurmatu 6 m. · Qāzah Chai · Little Hassār · Hassār · Fr. Tauq Meqil 12 m. · Well, D 40 · Panj Ali · Section B · B

E. H. PASCOE. Aug. 1918.
Reg. No. 4144 E 20.

Topography taken from T. C. 253.

Del. G. S. I. Calcutta.
Heliozincographed at the Survey of India Offices, Calcutta.

TAZAH KHURMATU AND TAUQ AREAS.

Scale, 1 inch = 1 mile.

Alluvium.

Upper (Conglomeratic) stage } Kurd series.
Lower stage }

Fars series.

Dips.

g „ gentle.

m „ moderate.

Vertical beds.

f Reversed fault, hading N. E.

Tel Jalāu
Tālāu (west)
Shurjah
Stony
Chardaghīl
Tel Kutish
Inhabited Village
Qāzah Chāi
Shamshi
Ford
Fr. Nukhailah 34 m.
BUSHAIRIYAH
Wall
SAREH TAPPAH
Sareh
Tāuqmaqīl Chāi
Tel Tāzah
TĀZAH KHURMĀTU
Khāwar R.
Jadidah
Tuwailah
Tel Magat
Ruins
Tel Lailān
KHAWAR R.
Unsurveyed
Tel Mustafah ?
Qamīsah ?
Abdul Ghanim ?
Yangīyah ?
TĀUQ
Hassān
Little Hassar
Well D40'
Well D45'
Well D50'
Tāuqmaqīl
SARACH DĀGH
Matārah
Panj Ali
Crest
Sq. C. L.
Rujaibāt
Tarjīl
Imām on hill
MATĀRAH DĀGH
Zain al Abidīn (Monastery on hill)
TĀUQ CFA.
Chavirgah
Ford
Tāuq Bridge
969
Shurawah

Topography taken from T. C. 211, T. C. 252 & T. C. 253.

E. H. PASCOE.
Reg. No. 1071. E 21

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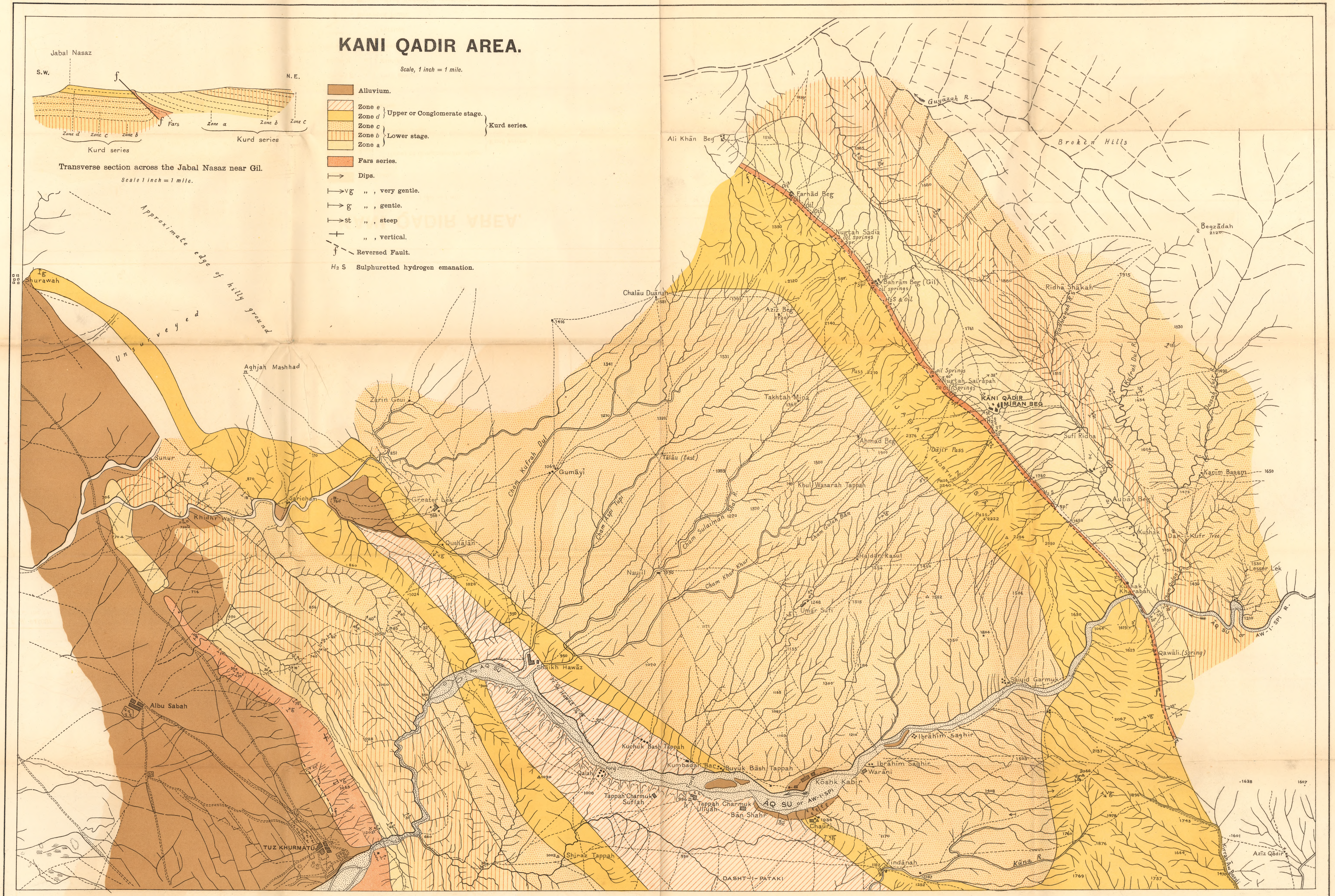
Memoirs, Vol. XLVIII, Pl. 7.



COUNTRY BETWEEN TUZ KHURMATU & KIFRI.

Scale, 1 inch = 1 mile.

- Alluvium.
- Pleistocene Conglomerate.
- Kurd series.
  - Upper or Conglomerate stage.
    - Zone *e*
    - Zone *d*
  - Lower stage.
    - Zone *c*
    - Zone *b*
    - Zone *a*
- Fars series.
- Dips.
- V.g „ very gentle.
- g „ gentle.
- Vertical beds.
- Contorted beds.
- Overfolded crest.
- Crests.
- Reversed fault.
- H_2S. Sulphuretted hydrogen.

Topography taken from T. C. 203 & T. C. 211.

E. H. PASCOE.

Reg. No. 1264. E 21

DIAGRAMMATIC SECTION JUST N. OF TUZ KHURMATU.

Scale, 1 inch = 1 mile.

DIAGRAMMATIC SECTION OPPOSITE SULAIMAN BEG, JUST N. OF THE STREAM.

Scale, 1 inch = 1 mile.

DIAGRAMMATIC SECTION OPPOSITE SULAIMAN BEG, JUST S. OF THE STREAM.

Scale, 1 inch = 1 mile

Del. G. S. I. Calcutta.

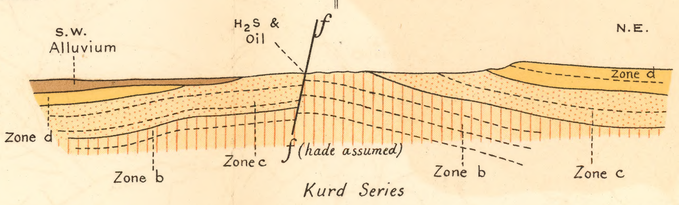
HELIO. S. I. O., CALCUTTA.

JABAL GILABAT AREA
BETWEEN
KIFRI AND QARAH TAPPAH.

Scale 1 inch = 1 mile.

- Alluvium.
- Pleistocene Conglomerate.
- Zone *e* / Zone *d* — Upper or Conglomerate stage. — Kurd series.
- Zone *c* / Zone *b* / Zone *a* — Lower stage. — Kurd series.
- Fars series.

Dips.
,, very gentle. v.g
,, gentle. g
Reversed fault. f
Sulphuretted hydrogen. H_2S.



TRANSVERSE SECTION ACROSS JABAL GILABAT A-A.
Scale, 1 inch = 1 mile.

E. H. PASCOE.
Reg. No. 1270. E 21

Topography taken from T. C. 145, T. C. 200-A & T. C. 203.

Del. G. S. I. Calcutta.
Helio. S. I. O., Calcutta.

JABAL HAMRIN

FROM OPPOSITE

QARAH TAPPAH

TO

TABLE MOUNTAIN.

Scale, 1 inch = 1 mile.

INDEX.

- Alluvium.
- Pleistocene or Early Recent Gravels.
- Zone *d* Conglomerate stage.
- Zone *c* } Lower stage. } Kurd series.
- Zone *b* }
- Dips.
- g ,, gentle.
- vg ,, very gentle.
- Pitching anticlinal crest.
- Vertical beds.

Topography taken from T. C. 98-C, T. C. 125-B & T. C. 145.

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Heliozincographed at the Survey of India Offices, Calcutta.